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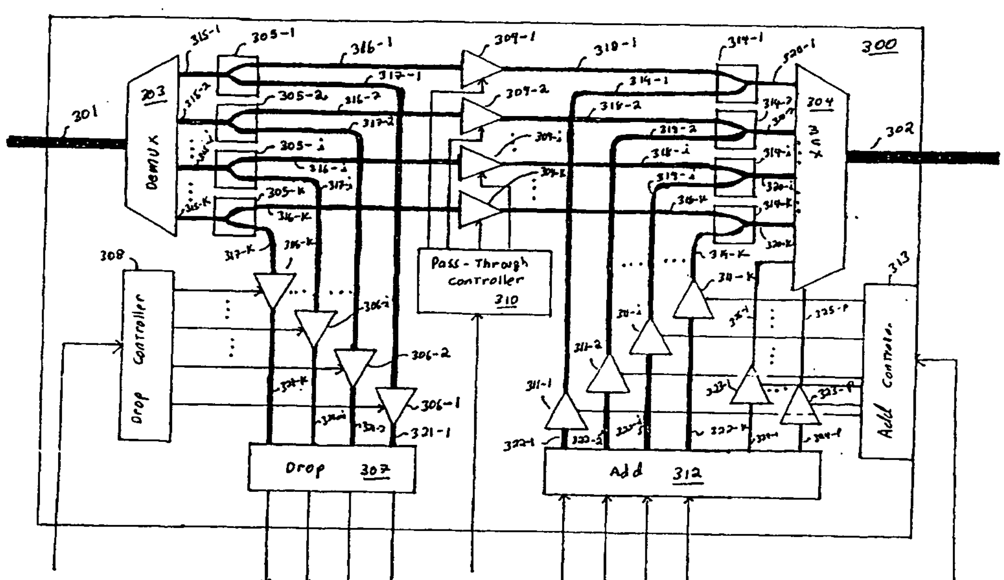

(57) Abstract: A dynamic programmable optical add/drop module for Dense Wavelength Division Multiplexed networking systems is presented. The optical add/drop module can be a drop module, an add module, or an add/drop module. Further, the optical add/drop module includes semiconductor optical amplifiers, allowing for programmability. Optical add/drop modules can selectively drop light beams of selected wavelengths. Furthermore, the optical add module can be programmed through semiconductor optical amplifiers to add data onto specific wavelengths. The optical add/drop module with semiconductor optical amplifiers has a fast switching speed and is highly versatile.

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DYNAMIC PROGRAMMABLE OPTICAL ADD/DROP MODULE

BACKGROUND

1. FIELD OF THE INVENTION

This invention relates to wavelength division multiplexed optical communication systems and, more particularly, to optical modules for adding or dropping optical signals on a wavelength division multiplexed optical network system.

2. DISCUSSION OF RELATED ART

Optical communications systems, and therefore the components of optical communications systems, are quickly being developed for high bandwidth optical data transmission. High bandwidth systems are in demand for telecommunications networks, metro-systems, local area networks, and cable television subscriber networks, for example.

In many networking systems, in order to transmit data from a plurality of sources to a plurality of receivers over a single medium, time-division multiplexing is employed. In time-division multiplexing, particular time slots are allotted to particular sources and a data signal from a single source is reconstructed by the receiver reading data from the appropriate time slots. The signal carrying capacity in time-division multiplexing on optical fibers is limited, however, by fiber dispersion and the need for high peak-power optical pulses.

The information carrying capacity of an optical fiber can be greatly enhanced using wavelength division multiplexing (WDM). In wavelength division multiplexing,

data signals are transmitted over an optical beam. The optical beam includes a plurality of light beams, each one of the plurality of light beams having light of a specified wavelength. A single fiber, therefore, can carry the optical beam with individual data signals on each of the plurality of light beams. In other words, data signals can be transmitted on different wavelengths of light through the optical fiber. Wavelength-division multiplexing can be combined with time-division multiplexing as well as other data transmission schemes (e.g., packet transmission) in order to transmit large volumes of data over the network at very high data transmission rates.

Most nodes on the network have the ability to receive signals directed to that node. When wavelength-division multiplexing is used, nodes typically receive signals from light of a subset of the available wavelengths propagating on the optical fiber. Nodes on the network, therefore, need the ability to "drop" one or more of the plurality of light beams so that data signals carried on those dropped light beams can be processed by node opto-electronics.

Additionally, at least one of the nodes on the network has the ability to couple signals onto the available light beams of individual wavelengths propagating on the optical fiber. These nodes, then, need to be able to "add" light of one or more of the different wavelengths to the corresponding one or more of the plurality of light beams.

Figure 2 shows a block diagram of an example conventional network node 210. Example node 210 receives optical signals from input fiber 211 and outputs optical signals to output fiber 212. Node 210 includes on optical unit 200. Although some embodiments of optical unit 200 can drop incoming light beams having multiple wavelengths, optical unit 200 drops light beams having wavelength λ_i and

adds for transmission optical signals having optical wavelength λ_i.

Optical detector 203 receives the light beam dropped by optical unit 200, the optical signal at wavelength λ_i thus dropped is further processed at node 201. Opto-electronic network 205 includes the computer systems, televisions, or other transmitter/receiver systems that utilize the data transmitted to node 210. In some cases, where node 210 transmits data as well as receives data, opto-electronic network 205 is coupled to optical source 204. Optical source 204 generates new optical signals in response to opto-electronic network 205. The new optical signals are transmitted on the carrier wavelength λ_i. The optical signal is added to the light beam of wavelength λ_i by optical unit 200.

Optical unit 200, as shown in Figure 2, includes demultiplexer 201 and multiplexer 202. Demultiplexer 201 receives input light beams from input fiber 211. Each of the input light beams includes light of one of the multiple wavelengths λ_1 through λ_K. Demultiplexer 201 spatially separates the input light beams according to their individual wavelengths.

Except for the light beam of wavelength λ_i, all of the input light beams from demultiplexer 201 are coupled to multiplexer 202. The light beam of wavelength λ_i is output from optical unit 200. Multiplexer 202 receives light of all wavelengths, including light of wavelength λ_i which is input to optical unit 200, and couples all of the light beams to output fiber 212. In some embodiments of add/drop modules such as add/drop unit 200, multiple input beams (each having a different wavelength) is dropped and multiple input beams are added. In some embodiments, input beams of different wavelengths are added than those that are dropped.

In some cases, all of the light beams on optical fiber 211 are dropped and opto-electronic network 205 detects the selected signals directed at it. Opto-electronic network 205 then arranges to add all of the data signals to output fiber 212. In that case, opto-electronic network 205 includes a significant amount of electronics and optical sources devoted to repeating optical signals that may not be utilized by node 210.

Conventionally, optical unit 200 is a fixed wavelength device, operating at a particular set of wavelengths $\{\lambda_i\}$, which is a subset of the wavelengths utilized by the network system. Problematically, optical add/drop 200 can not be easily reconfigured for other wavelengths. Additionally, optical add/drop 200 may include complicated, lossy, and expensive components such as optical circulators or micro-mechanical mirror arrays, creating additional expense and complication in an optical network system.

For example, U.S. Patent No. 5,982,518 to V. Mizrahi, issued Nov. 9, 1999, describes an optical add/drop that includes two optical circulators, two arrays of Bragg gratings, and an optical isolator. The optical add/drop described by Mizrahi is capable of coupling out of an incoming optical fiber multiple wavelengths of light, and coupling into the outgoing optical fiber multiple wavelengths of light. However, the wavelengths coupled out (or into) the optical add/drop are not themselves separated into individual wavelength light beams. Furthermore, Bragg grating arrays are temperature sensitive and therefore the wavelength of operation for such arrays may drift. Further, Bragg gratings are fixed wavelength devices. Also, the arrays of Bragg gratings themselves can not be easily changed. Therefore, the optical add/drop according to Mizrahi can not be

reconfigured or reprogrammed. Additionally, optical circulators are expensive and bulky devices.

Another optical add/drop device is described in U.S. Patent No. 5,960,133 to W. Tomlinson, issued Sep. 29, 1999. The optical add/drop device described by W. Tomlinson utilizes micromechanical mirrors in order to select particular wavelengths of light for coupling into or out of the optical add/drop device. Micromechanical mirrors provide the ability to select light beams of particular wavelengths from the array of wavelengths light on the optical fiber, thereby overcoming the problem of reconfiguring the system. However, production of micromechanical mirrors is complex and expensive. Additionally, the switching speeds of micromechanical mirrors is about several milliseconds and, therefore, is too slow for many applications. Additionally, devices with many movable parts (such as micromechanical mirrors) cause reliability problems.

Therefore, there is a need for versatile optical components, such as optical add and drop modules, that couple optical signals from an optical fiber to node opto-electronics and couple signals from the node opto-electronics onto the optical fiber.

SUMMARY

According to the present invention, a dynamic programmable optical unit is presented. Some embodiments can decouple ("drop") light from one or more of a plurality light beams carried by an input optical fiber. Some embodiments can couple ("add") light to one or more of a plurality of light beams on an output optical fiber. Each of the plurality of light beams includes light of a specified wavelength where the set of specified

wavelengths is predetermined for the networking environment that includes the dynamic optical unit.

Most embodiments of the dynamic optical unit are capable of dropping one or more of the plurality of light beams from the input optical fiber and adding to one or more of the plurality of light beams to the output optical fiber. In most embodiments, the ability to drop or add light beams is controllable either at the time of installation or during operation of the optical module. In some embodiments, the plurality of light beams from the input optical fiber is of a different set of predetermined wavelengths than the plurality of light beams to the output optical fiber.

One embodiment of the optical module includes a demutliplexor coupled to the input optical fiber to receive a plurality of light beams and at least one individually selectable optical amplifier coupled to the demultiplexer. Each of the at least one individually selectable optical amplifiers is coupled to receive at least a portion of light from one of the plurality of light beams. The at least one optical amplifier can provide programmable selectability to drop light of specific wavelengths from the light beams on the incoming optical fiber. The output beam from each of the at least one optical amplifier can be coupled to node opto-electronics outside of the optical module.

The optical amplifiers can function as gates, having an "on" or "off" state. Further, the optical amplifiers in the "on" state have a gain characteristic, amplifying the light beams incident on them. Further, in the "off" state, optical amplifiers provide excellent isolation, preventing the backward propagation of light.

In many embodiments, the optical amplifiers are semiconductor optical amplifiers. Semiconductor optical amplifiers have excellent switching times. Typical

switching times for semiconductor optical amplifiers are about 0.5 to 1 ns, a few orders of magnitude faster than currently available switching devices (such as mirror arrays), which operate in millisecond or microsecond time ranges.

Some embodiments further include a multiplexer that couples outgoing optical signals to one or more of a plurality of output light beams to be coupled to an output optical fiber. The output light beams may be coupled to the input light beams of the demultiplexer. Also, embodiments may include one or more individually selectable add optical amplifiers coupled to add light to one of the plurality of output light beams received by the multiplexer. The add optical amplifier can provide programmable selectability to add data signals to light beams of specific wavelengths on the outgoing optical fiber by switching the optical amplifier to an "on" or "off" state.

Yet other embodiments of the optical unit include a multiplexer that couples the plurality of output light beams to the optical fiber and at least one optical amplifier coupled between the node opto-electronics and the multiplexer. Optical data signals are added to one or more of the plurality of output light beams coupled to the optical fiber.

Additionally, some embodiments include at least one individually selectable optical amplifier coupled between a demultiplexer and a multiplexer, each of the at least one individually selectable optical amplifiers amplifying light from one of the plurality of input light beams and coupling an amplified beam to the multiplexer.

In some embodiments, multiple light beams may be coupled to a single optical amplifier. Semiconductor optical amplifiers typically have a wide enough band-width (about 70 to about 80 nm) to amplify more than one of the

wavelengths of light. In some instances, the band-width of a semiconductor optical amplifier can be tuned to accommodate several light beams.

In most embodiments, specific ones of the input light beams are selected for drop. Also, light of additional wavelengths can be added to the output light beams. Additionally, light of wavelengths corresponding to the input individual wavelength light beams that are dropped can also be added. Other embodiments of the invention, however, may independently receive and transmit signals on light of any of the available wavelengths on the input optical fiber and output optical fiber, respectively.

For example, in digital interactive television networks, data signals for each individual program may be delegated to one of the discreet wavelengths of light. Light of one wavelength may carry signals for multiple programming, where individual programming may be time-division multiplexed with other programming already carried on the light beams. A remaining number of light beams having selected discreet wavelengths of light may be dedicated to data communications between a consumer and a provider. The consumer, therefore, would select individual programming, at least in part, by selecting the wavelength of light that carries the data signal for that programming. Data is transmitted between the consumer and the provider on a light beam of a different wavelength.

In some embodiments of the invention, only one input light beam is selected for receipt and/or one individual wavelength of light is selected for addition at any given time. In other embodiments, multiple individual wavelength light beams may be selected at any given time.

Embodiments of the invention further include control opto-electronics that determines the gain or "on"/"off" state of each of the optical amplifiers. In some embodiments, the control opto-electronics includes

switches set by an installer so that the gain or "on"/"off" state of some or all of the optical amplifiers is set on installation. Some embodiments are externally controlled and set the characteristics of some or all of the optical amplifiers in response to control signals from the node opto-electronics.

These and other embodiments are further discussed below with respect to the following figures.

BRIEF DESCRIPTION OF THE FIGURES

Figure 1a shows an example of an optical network.

Figure 1b shows an example of another optical network.

Figure 2 shows a block diagram of a node included in the network of Figure 1.

Figure 3a shows a block diagram of an embodiment of an optical module according to the present invention.

Figure 3b shows a block diagram of another embodiment of an optical module according to the present invention.

Figure 4 shows a block diagram of a demultiplexer.

Figure 5 shows a block diagram of an optical amplifier.

Figure 6 shows a block diagram of an example node that includes a dynamic add/drop module according to the present invention.

In the figures, elements having the same or similar functions have the same designation.

DETAILED DESCRIPTION

Figure 1a shows an example optical network 100 having a plurality of nodes operating on a single fiber. Figure 1a shows, for example, a configuration of an optical loop

network 100 having nodes 101-1 through 101-N. Node 101-j designates an arbitrary one of nodes 101-1 through 101-N. Optical fiber 102 is a loop of optical fiber carrying light of multiple discreet wavelengths λ_1 through λ_K.

Wavelengths λ_1 through λ_K are typically part of a standard set of wavelengths preselected for transmitting data on network 100. An example of one such set of wavelengths recommended by the International Telecommunications Union (ITU) is given in Table 1. Sets of wavelengths having as many as 128 channels (individual wavelengths).

Table 1

Optical Channel	Central Wavelength (nm)	Central Frequency (THz)
λ_1	1548.51	193.6
λ_2	1549.32	193.5
λ_3	1550.12	193.4
λ_4	1550.92	193.3
λ_5	1551.72	193.2
λ_6	1552.52	193.1
λ_7	1553.33	193.0
λ_8	1554.13	192.9
λ_9	1554.94	192.8
λ_{10}	1555.75	192.7
λ_{11}	1556.55	192.6
λ_{12}	1557.36	192.5
λ_{13}	1558.17	192.4
λ_{14}	1558.98	192.3
λ_{15}	1559.79	192.2
λ_{16}	1560.61	192.1

Optical fiber 102 is shown as having sections 102-1 through 102-N. In many networks, each node 101-1 through 101-N is assigned a subset of the available multiple wavelengths, time slots on light beams of the individual wavelengths (i.e., each individual wavelength may be time division multiplexed as well as the entire scheme being wavelength division multiplexed), or addresses for packets sent on light beams of the individual wavelengths (i.e., packet transmission as well as wavelength division multiplexing). For example, in a video subscriber network each individual video program can be transmitted utilizing one light beam at a specified wavelength. With time-division multiplexing, multiple programs can be transmitted on each of the available light beams.

Some networks include more than one optical fiber for redundancy. Additionally, some networks are configure differently, such as hub and spoke networks or branching networks. Network 100 is shown as a circular loop for demonstration only. Most networks employ multiple fiber loops (not shown) for redundancy.

In Figure 1a, at least one of nodes 101-1 through 101-N has the ability to drop (i.e., read) one or more of the individual wavelengths of light from optical fiber 102. Additionally, at least one of nodes 101-1 through 101-N has the capability to add light of one or more of the individual wavelengths onto optical fiber 102. In most embodiments, each of nodes 101-1 through 101-N has the ability to read (i.e. drop) light beams of one or more of the individual wavelengths carried on optical fiber 102 and each of nodes 101-1 through 101-N has the ability to couple data signals into light of one or more of the wavelengths of light carried on optical fiber 102.

Figure 1b shows a broader optical network 150. Optical network 150 includes a long-haul network 151, a metro network 152, and an access network 153. Long-haul

network 151, metro network 152 and access network 153 are all examples of circular networks. Long-haul network 151 includes nodes 151-1 through 151-L coupled by optical fibers 155. Optical fibers 155 carry a plurality of light beams, each of the plurality of light beams having a predetermined wavelength from a set of wavelengths for the long-haul network environment.

Node 151-i, which is one of nodes 151-1 through 151-L, is also a member of metro network 152. Metro network 152 further includes nodes 152-2 through 152-M. The nodes of metro network 152 are coupled by optical fibers 156. Optical fibers 156 carry a plurality of light beams, each of the plurality of light beams having a predetermined wavelength from a set of wavelengths for the metro network environment, which may be different from the set of wavelengths for the long-haul network environment.

Node 152-j, which is one of nodes 152-2 through 152-M, is also a member of access network 153. Access network 153 further includes nodes 153-2 through 153-N. The nodes of access network 153 are coupled by optical fibers 157. Optical fibers 157 carry a plurality of light beams, each of the plurality of light beams having a predetermined wavelength from a set of wavelengths for the access network environment, which may be different from the set of wavelengths for the long-haul network environment. Node 153-k, which is one of nodes 153-2 through 153-N, is a hub of hub and spoke network 154. Network 154 includes nodes 154-1 through 154-O, all coupled to node 153-k through optical fibers carrying a plurality of light beams. Each of the plurality of light beams has a predetermined wavelength from a set of wavelengths for the network environment of network 154, which may be a different set of wavelengths from that of networks 151, 152 or 153.

Any of the nodes in networks 151, 152 or 153 may be as shown in Figure 2. However, at least one of the nodes in a network according to the present invention includes an optical device such as optical device 300 of Figure 3a. Figure 3a shows a dynamic optical device 300 according to the present invention. Optical device 300 is extremely versatile. Additionally, many embodiments of optical device 300 are programmable.

Optical device 300, as shown in Figure 3a, includes a demultiplexer 303 and a multiplexer 304. Other embodiments may include only one of demultiplexer 303 or multiplexer 304. Demultiplexer 303 is coupled to receive light carried on input fiber 301. Input fiber 301 carries data signals on a plurality of light beams, each of the plurality of light beams having one of a set of distinct wavelengths λ_1 through λ_K. The set of distinct wavelengths λ_1 through λ_K is the set of wavelengths chosen for utilization on the optical network environment of input fiber 301. An arbitrary one of wavelengths λ_1 through λ_K is designated λ_i. The set of distinct wavelengths can include any number of individual wavelengths. In most embodiments, the set of wavelengths λ_1 through λ_K is determined by an industry standards, such as the ITU, for that networking environment.

Data signals can be modulated in any fashion on the light beams. Additionally, data can be encoded in any fashion. Data can be encoded in any manner and transmitted in a time-division multiplexed mode on the discreet wavelengths of light, by burst packet transmission on the discreet wavelengths, or by any other fashion. Some common types of modulators for use in optical systems include lithium niobate ($LiNbO_3$) Mach-Zhender (MZ) modulators, indium phosphide (InP) Mach-

Zhender modulators, and indium phosphide (InP) electro-absorption (EA) modulators.

Demultiplexer 303 can be any device which is capable of spatially separating the input light beams, each of the input light beams having light of one of discreet wavelengths λ_1 through λ_K. An example of a phasar device utilized as a demultiplexer is shown in Figure 4. Phasar device 400 is compact and integrable into an optical circuit or a silicon optical bench (SiOB). Other examples of demultiplexers include the use of thin-film filters.

In most embodiments of the invention, demultiplexer 303 (Figure 3a) couples the light beams of each of the discreet wavelengths λ_1 through λ_K into a corresponding optical fiber 315-1 through 315-K. Each of the optical fibers 315-1 through 315-K can be coupled to a corresponding one of intensity splitters 305-1 through 305-K. Optical fiber 315-i in Figure 3a, for example, is coupled to intensity splitter 305-i. Intensity splitter 305-i splits the light beam of wavelength λ_i into two output beams and couples one beam into optical fiber 316-i and a second beam into optical fiber 317-i. In general, each of intensity splitters 305-1 through 305-K splits its input beam into two or more output beams, coupling a first output beam into optical fibers 316-1 through 316-K, respectively, and a second output beam into optical fibers 317-1 through 317-K, respectively. In some embodiments, each of intensity splitters 305-1 through 305-K can split its corresponding input beam into more than two beams and couple each of the beams into a separate optical fiber.

Intensity splitters 305-1 through 305-K can each be arranged to split the intensity of its corresponding input beam in any fashion between its two or more output beams. In many embodiments of the invention, for example, about 90% of the intensity of the light beam from optical fiber 315-i that is coupled to intensity splitter 305-i is

coupled to optical fiber 316-i and about 10% is coupled to optical fiber 317-i. Other embodiments can use any splitting of intensities. Further, some embodiments of the invention may have different intensity on each of intensity splitters 305-1 through 305-K, depending on particular applications of optical module 300.

Optical fibers 316-1 through 316-K can each be coupled to a corresponding one of optical amplifiers 309-1 through 309-K. In most embodiments, each of optical amplifiers 309-1 through 309-K are semiconductor optical amplifiers. Figure 5 shows a block diagram of a multiple quantum-well semiconductor optical amplifier that can be utilized as optical amplifiers 309-1 through 309-K.

Each of optical amplifiers 309-1 through 309-K is coupled to receive a corresponding light beam of wavelength λ_1 through λ_K, respectively, from the corresponding optical fibers 316-1 through 316-K, respectively. Optical amplifiers 309-1 through 309-K optically amplify the input light beam and couple the resulting light beam to a corresponding one of optical fibers 318-1 through 318-K. Optical fibers 318-1 through 318-K can be coupled to intensity splitters 314-1 through 314-K, respectively.

Intensity splitters 314-1 through 314-K combine each of the light beams from optical fibers 318-1 through 318-K with a light beam from a corresponding one of optical fibers 319-1 through 319-K and couples the resulting light beam to a corresponding one of optical fibers 320-1 through 320-K. Added signals to the output beam are input through optical fibers 319-1 through 319-K, where new data transmitted on light of wavelength λ_i to the optical network through add/drop module 300 is input through optical fiber 319-i to intensity splitter 314-i. Each of optical fibers 320-1 through 320-K, carrying data signals at wavelengths of λ_1 through λ_K respectively, is input to

multiplexer 304. Multiplexer 304 couples the light beams from each of optical fibers 320-1 through 320-K into output fiber 302.

In some embodiments, multiplexer 304 couples to a fiber in a networking environment having a different subset of wavelengths λ_1' through λ_P', where P is the number of available wavelenths in the networking environment that includes fiber 302. In that case, light beams of wavelength other than the set of wavelengths received is added at mutliplexer 304. In Figure 3a, add 312 is further optically coupled to optical amplifiers 323-1 through 323-P. Optical amplifiers 323-1 through 323-P are optically coupled to add 312 through fibers 324-1 through 324-P, respectively, and optically coupled to multiplexer 304 through optical fibers 325-1 through 325-P, respectively. Optical amplifiers 323-1 through 323-P are further coupled to add controller 313. Through optical amplifiers 323-1 through 323-P, optical device 300 can add light beams of wavelengths λ_1' through λ_P' to optical fiber 302.

In some embodiments, multiplexer 304 may be coupled directly to optical fibers 318-1 through 318-K and 319-1 through 319-K, relieving the need for separate intensity splitters 314-1 through 314-K.

Multiplexer 304 may be a phasar multiplexer, which is shown in Figure 4, or may be constructed similarly to an intensity splitter such as splitter 314-1 through 314-K arranged for combination of light beams. In some embodiments, intensity splitters 314-1 through 314-K combine the two input beams in a 1:1 ratio, other embodiments may utilize different mixing ratios. If multiplexer 304 is a phasar device, then intensity splitters 314-1 through 314-K are likely necessary to combine all light of each wavelength into a single input beam for each wavelength to multiplexer 304.

In many embodiments, for fewar than about 16 channels (i.e., K is less than about 16), intensity splitter 314-1 through 314-K can be reverse splitters. For more than about 16 channels, other phasar devices such as a phasar multiplexer (as shown in Figure 4) or a thin-film multiplexer can be utilized. In many embodiments, intensity splitters 314-1 through 314-K are arranged for a 50/50 combination and light beams are either on fibers 318 or on fibers 319, but not both.

Optical amplifiers 309-1 through 309-K are each electrically coupled to pass-through controller 310. Pass-through controller 310 controls the gain of each of optical fibers 309-1 through 309-K. In most embodiments, pass-through controller 310 can be controlled from outside of add/drop module 300. In some embodiments, pass-through controller 310 can be externally programmed to set the gain on each of optical amplifiers 309-1 through 309-K. Due to the speed of switching of solid state optical amplifiers, i.e. about one nanosecond, optical device 300 can provide fast device reconfiguration.

In some embodiments, pass-through controller 310 is preset or can be preset (e.g., via dip-switches or patch wires) to independently control the gain of each of optical amplifiers 309-1 through 309-K at the time of installation of add/drop module 300 into a network system.

In most embodiments, the gains of optical amplifiers 309-1 through 309-K are arranged to offset the loss of intensity of the pass-through light beam in add/drop module 300. The gain may also be set to offset the loss of intensity in optical fiber 301 (i.e., optical amplifiers 309-1 through 309-K may function as signal boosters).

In some instances, the gain of optical amplifiers 309-1 through 309-K can be dynamically set so that the intensity of each wavelength of output beam from add/drop

module 300 is a constant (i.e., the intensity of the output beam on optical fiber 318-i is related to the intensity of the light beam on optical fiber 319-i so that the combination of the two produces a beam with constant average intensity).

In some cases, one or more of optical amplifiers 309-1 through 309-K can be set to 0 in order to provide a beam-block to through signals. For example, in optical ring network 100 (Figure 1) individual packets of data need to be removed completely from optical fiber 102. If individual packets are not removed after they are transmitted, they will continue to circulate (being amplified by optical amplifiers in each of nodes 101-1 through 101-N) and contribute to unwanted noise or otherwise interfere with further transmission of data on optical fiber 102.

Light beams from optical fibers 317-1 through 317-K can be coupled into a corresponding one of optical amplifiers 306-1 through 306-K. The light beam of wavelength λ_i carried on optical fiber 317-i is coupled into optical amplifier 306-i, for example. Optical amplifiers 306-1 through 306-K each amplify the light beam from the corresponding optical fiber 317-1 through 317-K and couples the amplified light beam to a corresponding one of optical fibers 321-1 through 321-K. Drop controller 308 is electrically coupled to each of optical amplifiers 306-1 through 306-K in order to independently control the gain of optical amplifiers 306-1 through 306-K. In many embodiments, the gain of optical amplifiers 306-1 through 306-K is predetermined and drop controller 308 switches the state of each of optical amplifiers 306-1 through 306-K between an "on" state and an "off" state.

In some embodiments of the invention, drop controller 308 is externally programmable to turn on (the "on" state) or off (the "off" state) one or more of optical amplifiers

306-1 through 306-K. The gain of the one or more of optical amplifiers 306-1 through 306-K that is turned on can be predetermined, set on installation (e.g., through dip switches or on-board jumper wires), or externally programmed. In some embodiments, drop controller 308 includes installer setable switches (e.g., dip switches) to separately set the gain of each of optical amplifiers 306-1 through 306-K. Further, in other embodiments drop controller 308 is preset to control the gains of each of optical amplifiers 306-1 through 306-K.

Optical fibers 321-1 through 321-K, carrying the output beams from optical amplifiers 306-1 through 306-K, is shown coupled to drop module 307. Drop module 307 represents the output coupler, coupling the selected data signals from add/drop module 300. In some embodiments, optical fibers 321-1 through 321-K are output directly from add/drop module 300. In that case, the drop output signals from add/drop module 300 is carried optically on optical fibers 321-1 through 321-K. In other embodiments, drop module 307 multiplexes the light beams from optical fibers 321-1 through 321-K into one or more output optical fibers. In yet another embodiment of the invention, drop 307 includes one or more optical detectors in order to convert the data signals carried by the light beams on optical fibers 321-1 through 321-K into output electrical signals. In most such embodiments, each optical fiber 321-1 through 321-K is coupled to a single detector so that the detector can be optimized for detection of that wavelength.

Some embodiments include the ability to add optical signals to one or more of the output light beams. In Figure 3a, add module 312 receives signals into optical module 300 that are to be transmitted on output optical fiber 302. In some embodiments, add module 312 may be optical couplers so that data input signals to optical

module 300 are optical. In that case, add module 312 couples optical fibers 322-1 through 322-K directly out of optical module 300 so that optical fibers 322-1 through 322-K receive data signals on light of wavelengths λ_1 through λ_K, respectively.

In other embodiments, add module 312 receives electrical signals, including data signals to be transmitted as optical signals. In that case, add module 312 includes one or more light sources (e.g., lasers) which can be tuned to each of wavelengths λ_1 through λ_K and appropriately coupled to optical fibers 322-1 through 322-K. In most such embodiments, add module 312 includes a separate laser for each of wavelengths λ_1 through λ_K coupled to optical fibers 322-1 through 322-K, separately. Each of the separate lasers may be modulated to transmit the data received on the electrical input lines. Other embodiments modulate the light beams in other ways, for example by modulating the gain of the appropriate one of optical amplifiers 311-1 through 311-K, in order to place data signals on the light beams. Further, add module 312 may be programmable to independently address the light source to each of optical fibers 322-1 through 322-K and direct input data to the appropriate light source for transmission at a particular wavelength λ_i.

Optical fibers 322-1 through 322-K are coupled to optical amplifiers 311-1 through 311-K, respectively. Optical amplifiers 311-1 through 311-K are further coupled to intensity splitters 314-1 through 314-K, respectively, in order to insert optical data onto output optical fiber 302. The gains of optical amplifiers 311-1 through 311-K are controlled by add controller 313.

In some embodiments, add controller 313 is externally programmed to set the gains of optical amplifiers 311-1 through 311-K. In some cases, add controller 313 is

externally programmed to turn on one or more of optical amplifiers 311-1 through 311-K to a preset gain level. The preset gain level, in some embodiments, can be set by an installer (e.g., by setting dip switches). Add controller 313 is preset to set the gain of one or more of optical amplifiers 311-1 through 311-K. In most embodiments, add controller 313 cooperates with add module 312 so that add module 312 outputs light beams to one or more of optical amplifiers 311-1 through 311-K that are activated (e.g., placed in the "on" state) by add controller 313.

In one embodiment of the invention, optical module 300 is constructed on a single semiconductor chip. Demultiplexers, multiplexers, optical amplifiers, and intensity splitters can all be implemented on a single integrated optical circuit. Further, the optical fibers can be replaced by waveguides constructed on the integrated circuit. Further, control circuitry can also be constructed on the semiconductor chip.

Figure 3a shows an example embodiment where fiber 301 and fiber 302 can both carry light beams having wavelengths λ_1 through λ_K. In addition, optical fiber 302 can also carry wavelengths λ_1' through λ_P'. In some embodiments, optical module 300 receives light beams of a set of wavelengths λ_1 through λ_K from optical fiber 301 and is coupled to optical fiber 302 which carries a different set of wavelengths λ_1' through λ_P'. In that case, light beams dropped by optical device 300 and added by optical device 300 may be of differing wavelengths. In one particular embodiment, optical device 300 receives only a subset of light beams of the available wavelengths and adds light beams, still within the original set of wavelengths, but different from those actually received. In that case, not all of optical fibers 315-1 through 315-K are present in optical device 300.

Figure 3a shows an embodiment of an add/drop optical module that both drops optical signals and adds optical signals to the network system. Other embodiments of the invention may only drop or only add optical signals. One embodiment, for example, includes only demultiplexer 303 and at least one of optical amplifiers 306-1 through 306-K. Another embodiment includes only multiplexer 304 and at least one of optical amplifiers 311-1 through 311-K. Other embodiments may include one or more of intensity splitters 305-1 through 305-K, intensity splitters 314-1 through 314-K, or optical amplifiers 309-1 through 309-K. One skilled in the art will recognize numerous configurations of optical devices according to the present invention, each of which is intended to be within the scope of this disclosure.

Figure 3b shows a block diagram of a specific example of an embodiment of an optical module 350 according to the present invention. Optical module 350 receives signals from input optical fiber 370 and couples signals to output fiber 371. Optical module 350 includes 4-channel demultiplexer 351, 8-channel multiplexer 352, 1X2 splitters 354-1 through 354-4, and amplifier block 358. Amplifier block 358 includes optical amplfiers 355-1 through 355-4 and optical amplifiers 357-1 through 357-4. Optical module 350 is mounted within casing 367. Casing 367 can be any material that encloses optical module 350.

Demultiplexer 351 is coupled to input port 353 to receive light beams from input fiber 370. Input fiber 370 carries four light beams having wavelenghts λ_1 through λ_4, respectively. Demultiplexer 351 spatially separates the four light beams, which are then coupled into 1X2 splitters 354-1 through 354-4. Splitters 354-1 through 354-4 each split one of the four light beams into a first beam and a second beam. The first beam of each of splitters 354-1 through 354-4 is coupled into optical

amplifier 355-1 through 355-4, respectively. The output signals from optical amplifiers 355-1 through 355-4 are coupled to output ports 363-1 through 363-4, respectively, thereby dropping each of the the four light beams.

The second beam from each of splitters 354-1 through 354-4 are coupled into 8-channel multiplexer 352. Further, optical amplifers 357-1 through 357-4 are coupled to add input ports 364-1 through 364-4, respectively, to receive new light beams to be added to output optical fiber 371. The new light beams, in some embodiments, may each be of different wavelengths than the set of wavelengths λ_1 through λ_4 of the light beams carried by input optical fiber 370. The output signals from optical amplifiers 357-1 through 357-4 are coupled into multiplexer 352. The output signal from multiplexer 352 is coupled through output port 372 to output optical fiber 371.

In most embodiments optical amplifiers 355-1 through 355-4, 356-1 through 356-4, and 357-1 through 357-4 have either an "on" state or an "off" state. Optical amplifiers 355-1 through 355-4 are coupled through connector 359 to control ports 360-1 through 360-4 and optical amplifiers 357-1 through 357-4 are connected through connector 356 to control ports 362-1 through 362-4. Each of optical amplifiers 355-1 through 355-4 and 357-1 through 357-4 can be controlled by signals at connectors 360-1 through 360-4 and 362-1 through 362-4, respectively. Therefore, optical module 350 is dynamically programmable.

Demultiplexer 351 and multiplexer 352 each further includes a heater element. Demultiplexer 351 is coupled to heater ports 365 to receive heater power and multiplexer 352 is coupled to heater ports 366 to receive heater power.

Figure 4 shows a diagram of a phase device 400. Phase device 400 is either a multiplexer or a demultiplexer, depending on the direction of light propagation through the device. In demultiplexer operation, light having multiple wavelengths enters free propagation region 403 from optical fiber 401. Optical fiber 401 can carry a light beam of discreet wavelengths λ_1 through λ_K, with λ_i being an arbitrary one of the wavelengths. As has been previously discussed, in wavelength-division multiplexing the discreet wavelengths λ_1 through λ_K are preselected to be compatible with the network system. Phasar device 400 includes waveguide array 402-1 through 402-K that is matched to the discreet wavelengths λ_1 through λ_K.

Phase device 400 can be constructed on, for example, a silicon wafer. Additionally, phase device 400 may include a heater element 406 in order to avoid temperature affects in the performance of phase device 400. In many embodiments, heater element 406 holds the temperature of phase device 400 to about 70° C.

The beam of light entering the free propagation region 403 diverges and is coupled into waveguide array 402-1 through 402-K. The length of each waveguide in waveguide array 402-1 through 402-K is chosen such that the optical path length difference between adjacent waveguides equals an integer multiple of the central wavelength of phasar device 400. For the central wavelength, therefore, the electromagnetic fields of the light beams in waveguides 402-1 through 402-K will arrive at an output aperture 404 with phase differences of integer multiples of 2π. These fields, therefore, add constructively, reproducing the field distribution for the central wavelength light that is incident at the input of free propagation 403 at output aperture 404. This

reconstructed beam can be coupled to an individual optical fiber output 405.

Optical beams of other wavelengths will constructively interfere at other points on output aperture 404 corresponding to points were optical path differences along the waveguide array 402 for that wavelength of light corresponds to phase differences for that wavelength of multiple integers of 2π. Each of the separate beams propagates along a different path can be coupled into one of optical fibers 405 so that each of discreet wavelengths λ_1 through λ_K is coupled to one of optical fibers 405-1 through 405-K, respectively.

Phasar device 400, with input from optical fibers 405, can also operate as a multiplexer. Light of individual wavelengths λ_1 through λ_K from optical fibers 405-1 through 405-K, respectively, is coupled into phasar device 400 at aperture 404 and is coupled to optical fiber 401 at free propagation region 403. Phasar based demultiplexer are further discussed in M. Smit, "PHASAR-Based WDM-Devices: Principles, Design and Applications," IEEE J. of Selected Topics In Quantum Electronics, Vol. 2, No. 2, p. 236-250. However, for K less than about 16, it may be simpler to utilize reversed intensity splitters to provide a multiplexing function.

Figure 5 shows an example of a semiconductor optical amplifier 500. Optical amplifier 500 includes a substrate 501 and an active region 502. In most cases, the active region is InGaAs based technology. Optical amplifier 500 is coupled to an input optical fiber 503 and an output optical fiber 504.

Optical amplifier 500 is coupled to a voltage source V_g in active region 502 and a ground at substrate 501. If unpowered, active region 502 absorbs incident light. When a voltage is supplied at V_g, then charge carriers in active region 502 are promoted to higher energy levels. Photons

incident on active region 502, instead of being absorbed, initiate transitions from the higher energy levels into lower levels and the production of further photons, as in a laser device. Therefore, the amount of amplification (i.e., the number of photons emitted by active region 502 for each photon incident on active region 502) is dependent on the number of electrons held in the excited state, which depends on the current and voltage supplied at V_g.

If light is incident on active region 502 from optical fiber 503, light is emitted from active region 502 and coupled into optical fiber 504. The gain of amplifier 500 is determined by an input signal at V_g. In many instances, optical amplifier 500 has an "on" state when V_g is above a threshold level and an "off" state when V_g is below the threshold level.

In some cases, a current source 505 is provided to add current to amplifier 500, turning SOA 505 "on" or "off." For example, in a typical SOA a current of 40 mA may turn the SOA on with a gain of 5 dB at 1550 nm and 2.5 dB at 1530 nm. The SOA may saturate at 100 mA, providing a gain of 0 dB at 1530 nm and 5 dB at 1550 nm.

Semiconductor optical amplifiers (SOAs) have several advantageous properties. SOAs are fast switching (on the order of about 0.5 to about 1 ns), making them very attractive for dynamic, programmable optical systems requiring fast switching times. Additionally, SOAs are easlity integrated with other photonic devices in a planar waveguide.

The substitute of conventional bulk InGaAsP gain regions with multiple quantum well (MQW) technologies yields further advantages for SOAs. For example, the saturation output power is enhanced, allowing for high gains. MQW-SOAs typically have a broad-band gain spectrum, allowing for amplification over a broad range of

wavelengths (about 70 to 80 nm in some cases). MQW-SOAs further yield low noise figures, approaching the quantum limit. Polarization sensitivity of the MQW-SOA can be overcome successfully by employing both tensile and compressively strained quantum wells in a single active layer. Further advantages for utilizing multiple quantum well semiconductor optical amplifiers include their reliability, linearity of their amplification with signal input power, and reliable threshold current densities.

One skilled in the art is familiar with the use and operation of such semiconductor optical amplifiers. A further discussion of such optical amplifiers and the operation of such optical amplifiers is given in This, et al., "Progress in Long-Wavelength Strained-Layer InGaAs(P) Quantum-Well Semiconductor Lasers and Amplifiers," IEEE J. Quantum Elect., Vol. 30, No. 2, p. 477-499 (Feb., 1994), herein incorporated by reference in its entirety.

Figure 6 shows a block diagram of an add/drop module 300 according to the present invention in a node 600 of an optical network 610. Optical network 610 of which node 600 is a member can be ring network, as shown in Figure 1, or any other configuration of network. Input light beams having discreet wavelengths λ_1 through λ_K, each of which can be modulated to carry data signals, are transmitted on input optical fiber 601. Input optical fiber 601 is coupled to add/drop module 300. Output light beams having discreet wavelengths λ_1 through λ_K, carrying data signals, are coupled out of add/drop module 600 to output optical fiber 602.

In the embodiment of add/drop module 300 shown in Figure 6, pass-through controller 310 (Figure 3a) is a series of switches (e.g., a dip switch) which are set by an installer to provide a predetermined gain signal to each of optical amplifiers 309-1 through 309-K. In node 600, pass-through controller 310 is set to pass all of the

light beams except for the light beam having wavelength λ_i. In other words, the gains of all of optical amplifiers 309-1 through 309-K except for optical amplifier 309-i are set to amplify light. Amplifier 309-i is off and therefore acts as a beam block.

Drop controller 308 is externally programmed by node opto-electronics 607 to selectively turn on one or both of optical amplifiers 305-i and 305-n, thereby selecting one or both light beams of wavelengths λ_i and λ_n to drop. All of the remaining optical amplifiers are off. In the example shown in Figure 6, then, none of the light beams except for the light beams of wavelengths λ_i and λ_n are dropped at node 600. In other applications, such as for subscriber television networks for example, node opto-electronics 607 can selectively direct drop controller 308 to activate any one or more of optical amplifiers 305-1 through 305-K in order that node 600 can receive data carried by any one of the available light beams.

In the embodiment shown in Figure 6, only light beams of wavelength λ_i and λ_n are dropped. Drop module 307 is an optical coupler for all K of optical fibers 321-1 through 321-K, but in the application shown in Figure 6 only optical fibers 321-i and 321-n (Figure 3) are coupled out of add/drop module 300, through drop module 307. The remaining ones of optical fibers 321-1 through 321-K are not utilized.

Optical fiber 321-i is coupled to optical detector 603 and optical fiber 321-n is coupled to optical detector 604. Therefore, optical detector 603 receives light of wavelength λ_i and optical detector 604 receives light of wavelength λ_n. The electrical data signal from optical detectors 603 and 604 is received by node opto-electronics 607.

Node opto-electronics 607 can output optical signals for addition to output optical fiber 602 as well. In node 600 of Figure 6, node opto-electronics 607 outputs data signals to optical source 605 and optical source 606. Optical source 605 outputs light, modulated to carry the data signal transmitted to it, of wavelength λ_q and optical source 606 outputs light, modulated to carry the data signal transmitted to it, of wavelength λ_p. Optical source 605 is coupled, through add module 312, to optical fiber 322-q and optical source 606 is coupled to optical fiber 322-p. Each of optical fibers 322-q and 322-p are one of optical fibers 322-1 through 322-K of add/drop module 300. Node opto-electronics further outputs control signals to add controller 313 so that optical amplifiers 311-q and 311-p are turned on when there is data to transmit on light of wavelengths λ_q and λ_p, respectively. Add controller 313 of add/drop module 300 in node 600 is arranged such that all of the remaining optical amplifiers 311-1 through 311-K are off, allowing no light input to multiplexer 304 from add module 312.

In some embodiments of add/drop module 300, optical detectors 603 and 604 are included into drop module 307. Further, light sources 605 and 606 can be included in add module 312. Further, add/drop module 300 can be utilized with a wave-length division multiplexing scheme having any number of discreet wavelengths and any data modulation scheme.

The above described embodiments are demonstrative only. One skilled in the art will recognize numerous obvious variations, which are considered to be within the scope of this disclosure. As such, the invention is limited only by the following claims.

CLAIMS

I claim:

1. An optical module, comprising:

a demultiplexer coupled to an input fiber to receive a plurality of input light beams, each of the plurality of input light beams having a discrete wavelength of light;

at least one drop optical amplifier coupled to the demultiplexer to receive at least a portion of one of the plurality of input light beams; and

a drop module coupled to receive an output light beam from each of the at least one optical amplifier and provide a signal external to the module.

2. The module of Claim 1, wherein the demultiplexer is a phasar device.

3. The module of Claim 1, further including a drop controller coupled to control the at least one drop optical amplifier.

4. The module of Claim 3, wherein the at least one drop optical amplifier has an on state and an off state.

5. The module of Claim 1, wherein the at least one drop optical amplifier is a multiple quantum well solid state amplifier.

6. The module of Claim 1, further including a multiplexer that couples a second plurality of output light beams to an output fiber.

7. The module of Claim 6, wherein at least one of the second plurality of output light beams is coupled to one of the plurality of input light beams.

8. The module of Claim 7, further including at least one intensity splitter, the at least one intensity splitter coupled to receive one of the plurality of input light beams and split it into a first beam and a second beam, the first beam being coupled to one of the second plurality of output light beams and the second beam being coupled to one of the at least one drop optical amplifiers.

9. The module of Claim 7, wherein a booster optical amplifier is coupled between each of the at least one of the plurality of output light beams and the corresponding one of the plurality of input light beams.

10. The module of Claim 7, further including a pass-through controller controlling the gain of the booster optical amplifier.

11. The module of Claim 7, further including at least one output intensity splitter, each of the at least one output intensity splitter coupled to receive a first beam and a second beam and to output one of the second plurality of output light beams, the first beam coupled to receive one of the plurality of input light beams, and the second beam coupled to receive light from one of a plurality of add optical amplifiers.

12. The module of Claim 6, further including at least one add optical amplifier coupled each coupled to receive an output beam and coupled to one of the at

least one of the second plurality of output light beams.

13. The module of Claim 12, wherein the at least one add optical amplifier is a multiple quantum well solid-state amplifier.

14. An optical module, comprising:

a multiplexer coupled to an output fiber to transmit a plurality of output light beams, each of the plurality of output light beams having a discrete wavelength of light;

at least one add optical amplifier coupled to the multiplexer to add light to at least one of the plurality of the input light beams; and

an add module coupled to receive data signals and provide a light beam to each of the at least one add optical amplifier.

15. The module of Claim 14, wherein the multiplexer is a phasar device.

16. The module of Claim 14 wherein the at least one add optical amplifier is a multiple quantum well solid state optical amplifier.

17. The module of Claim 14, further including an add controller coupled to control the at least one add optical amplifier.

18. The module of Claim 17, wherein the gain settings for each of the at least one add optical amplifiers is set in response to external control signals.

19. A method of dropping data from an optical network, comprising:

demultiplexing light from an input fiber to obtain a spatially separated array of light beams, each of the array of light beams an individual wavelength; and

controllably amplifying a portion of at least some of the plurality of light beams.

20. The method of Claim 19, further including multiplexing output light beams to an output fiber.

21. The method of Claim 20, further including controllably amplifying a portion of at least one of the input light beams to form a corresponding at least one of the output light beams.

22. The method of Claim 19, further including splitting at least one of the input light beams into a first beam and a second beam, the first beam being coupled to a corresponding one of the output light beams, the second light beam being coupled to a corresponding one of the at least one drop optical amplifier.

23. A method of adding optical data to an optical network, comprising:

amplifying at least one optical light beam to form an output light beam having one of a set of discreet wavelengths, and

multiplexing the output light beam with at least one other output light beam to coupled the output light beam to an output fiber.

24. A network node, comprising:

a dynamic optical module coupled to receive an input light beam from the network and coupled to transmit an

output light beam to the network, the dynamic optical module including setable gain controls for at least one optical amplifier;

a node opto-electronics coupled to receive signals from the dynamic optical add/drop module and transmit data signals to the dynamic optical add/drop module.

25. The node of Claim 24, wherein the gain controls include controls for optical amplifiers for dropping light beams from the network.

26. The node of Claim 24, wherein the gain controls include controls for optical amplifiers on pass through light beams.

27. The node of Claim 24, wherein the gain controls include controls for optical amplifiers for adding optical signals to the network.

28. The node of Claim 24, wherein the gain controls are setable by a system installer.

29. The node of Claim 24, wherein the gain controls are dynamically set by node opto-electronics.

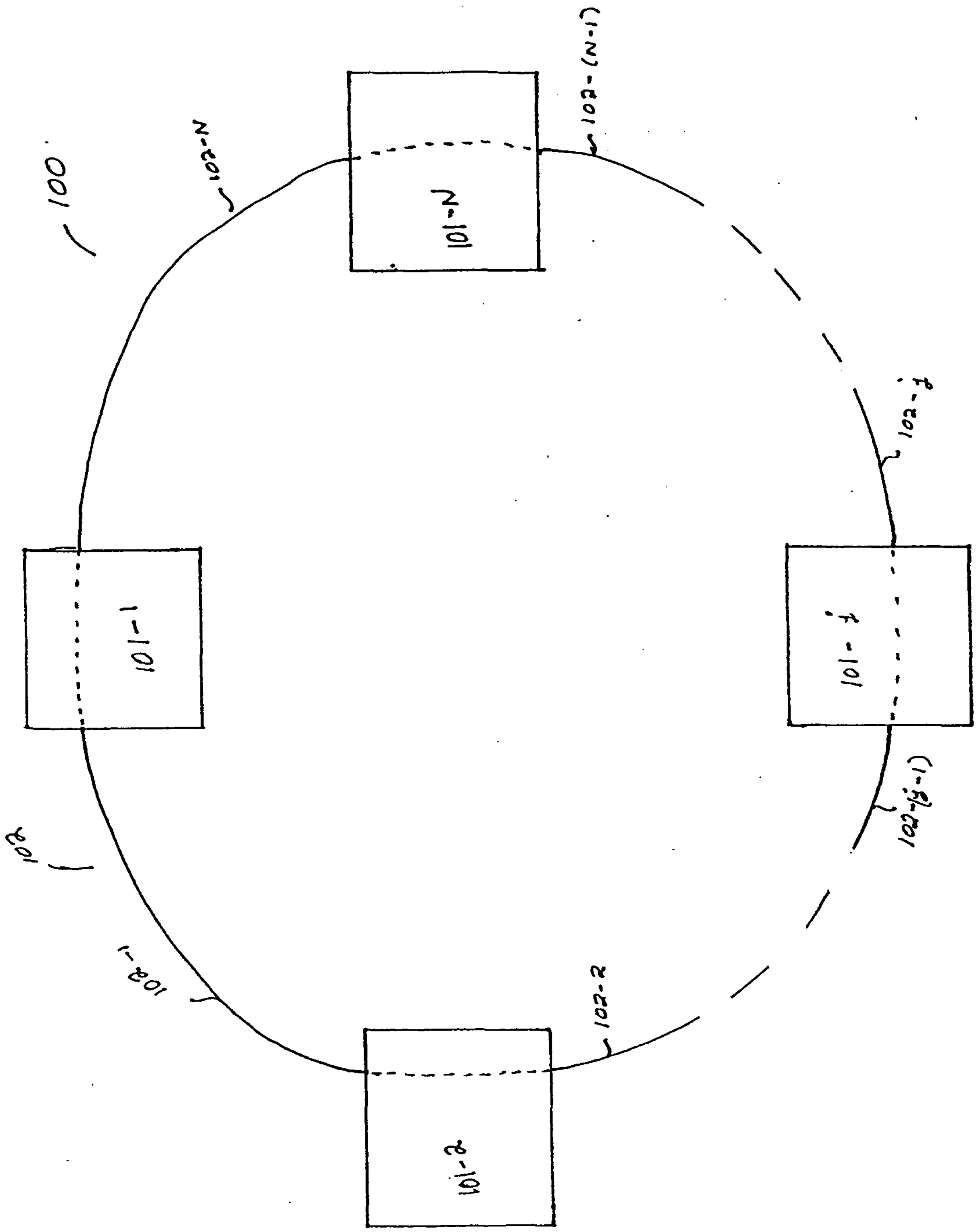
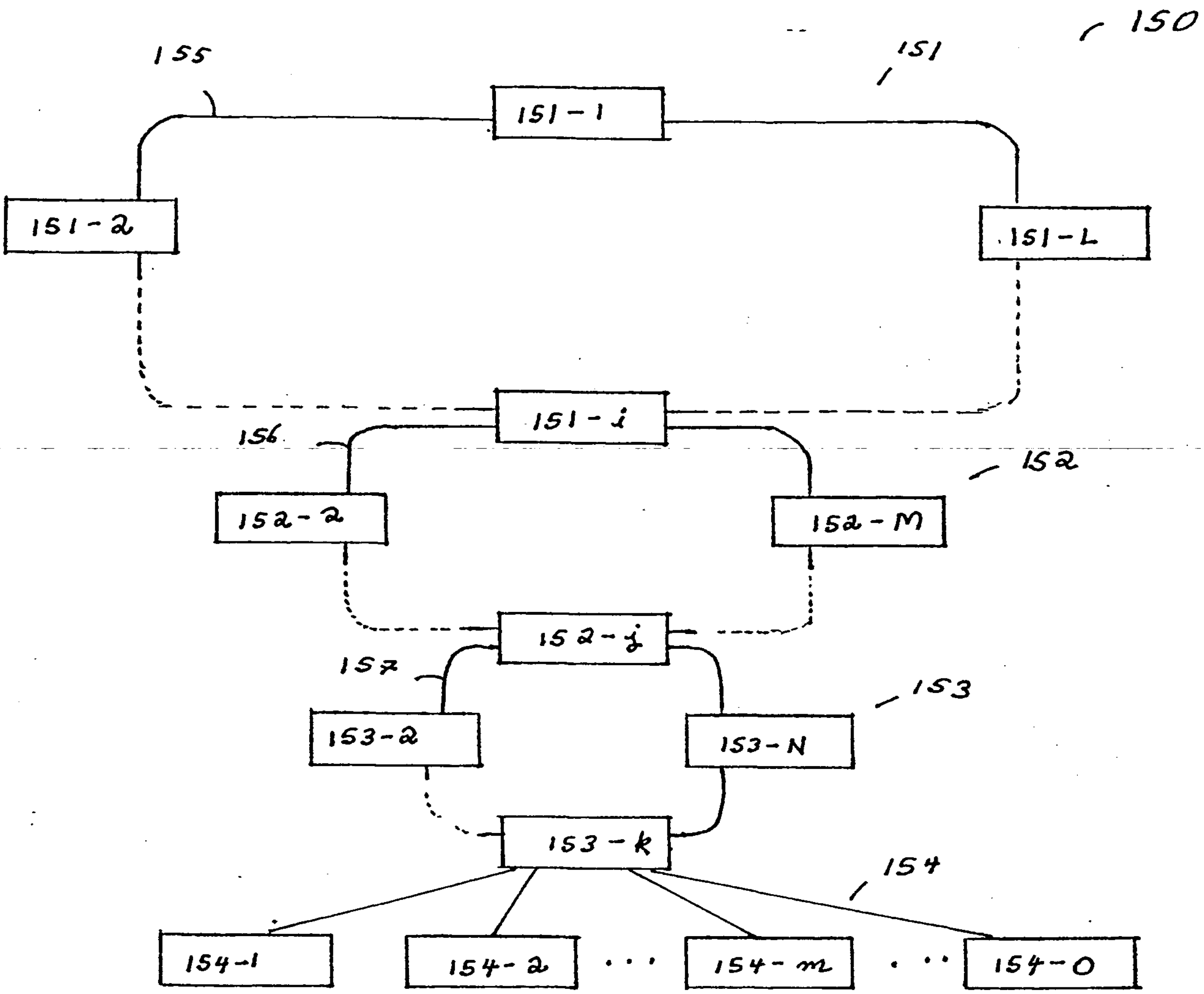


Figure 1a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152-2
152-M
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153-2
153-N
153-k
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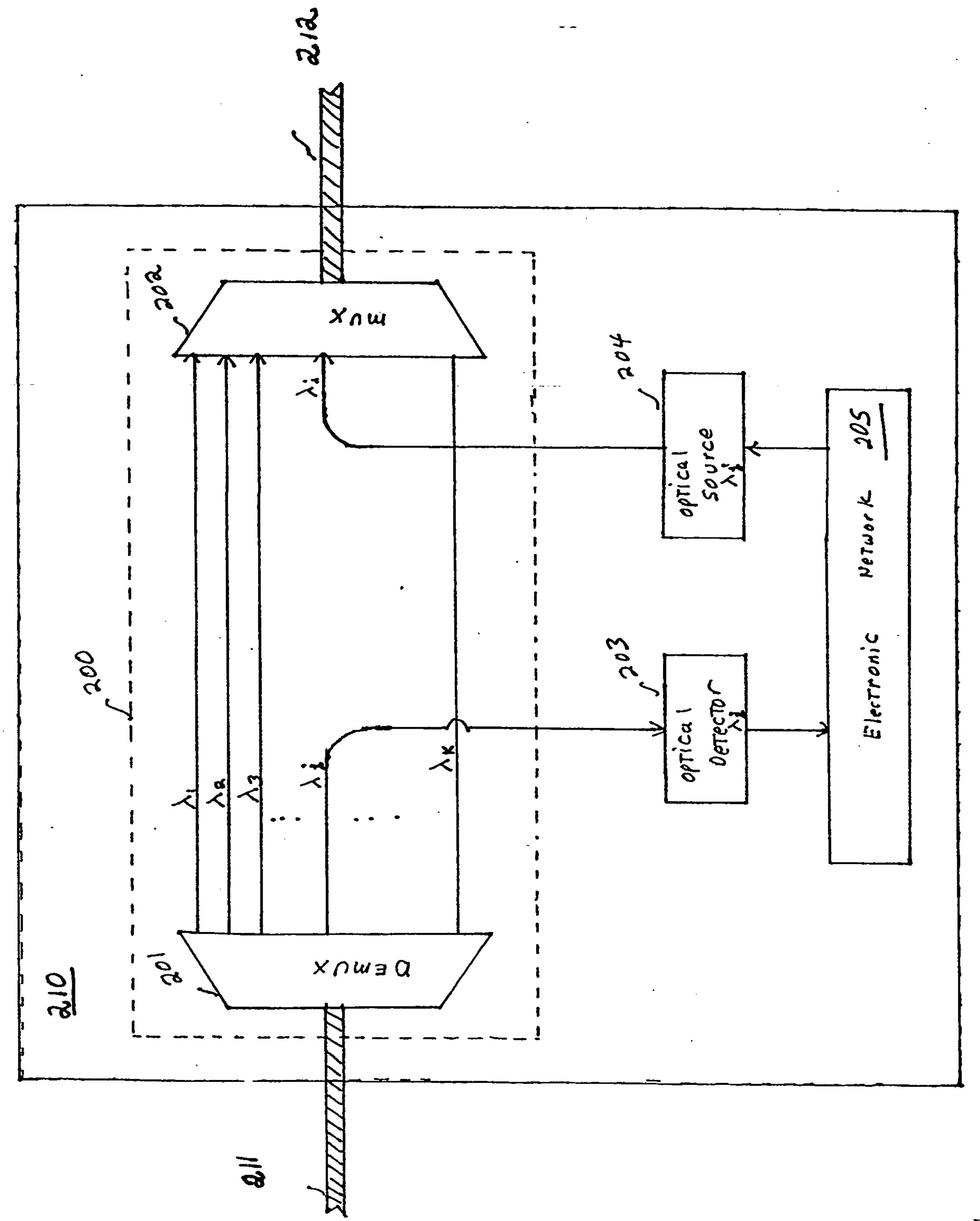
154-1
154-2
154-m
154-O

Figure 1b

Figure 2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mux
201
Demux
204
optical source
203
optical Detector
Electronic Network
205
211

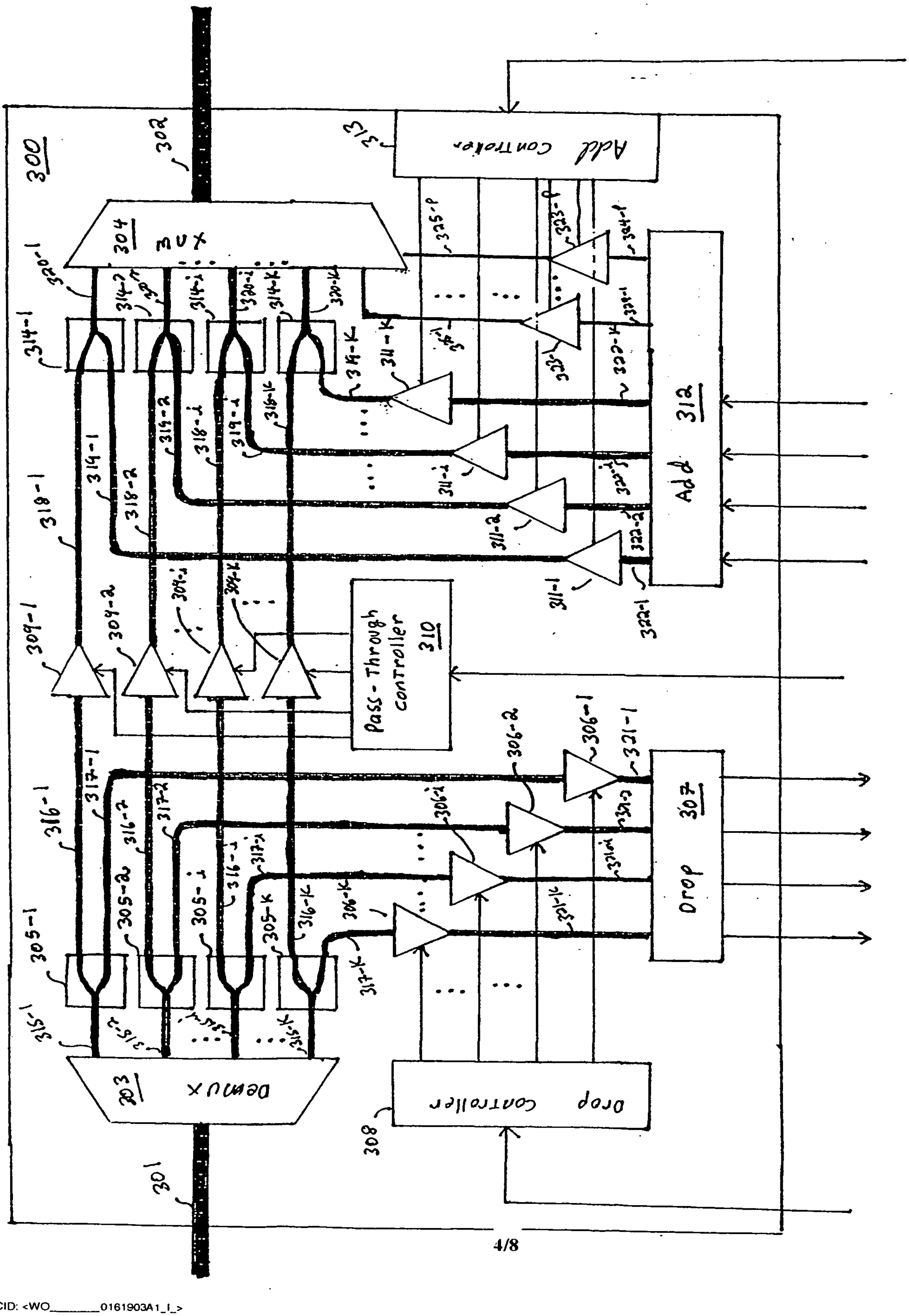
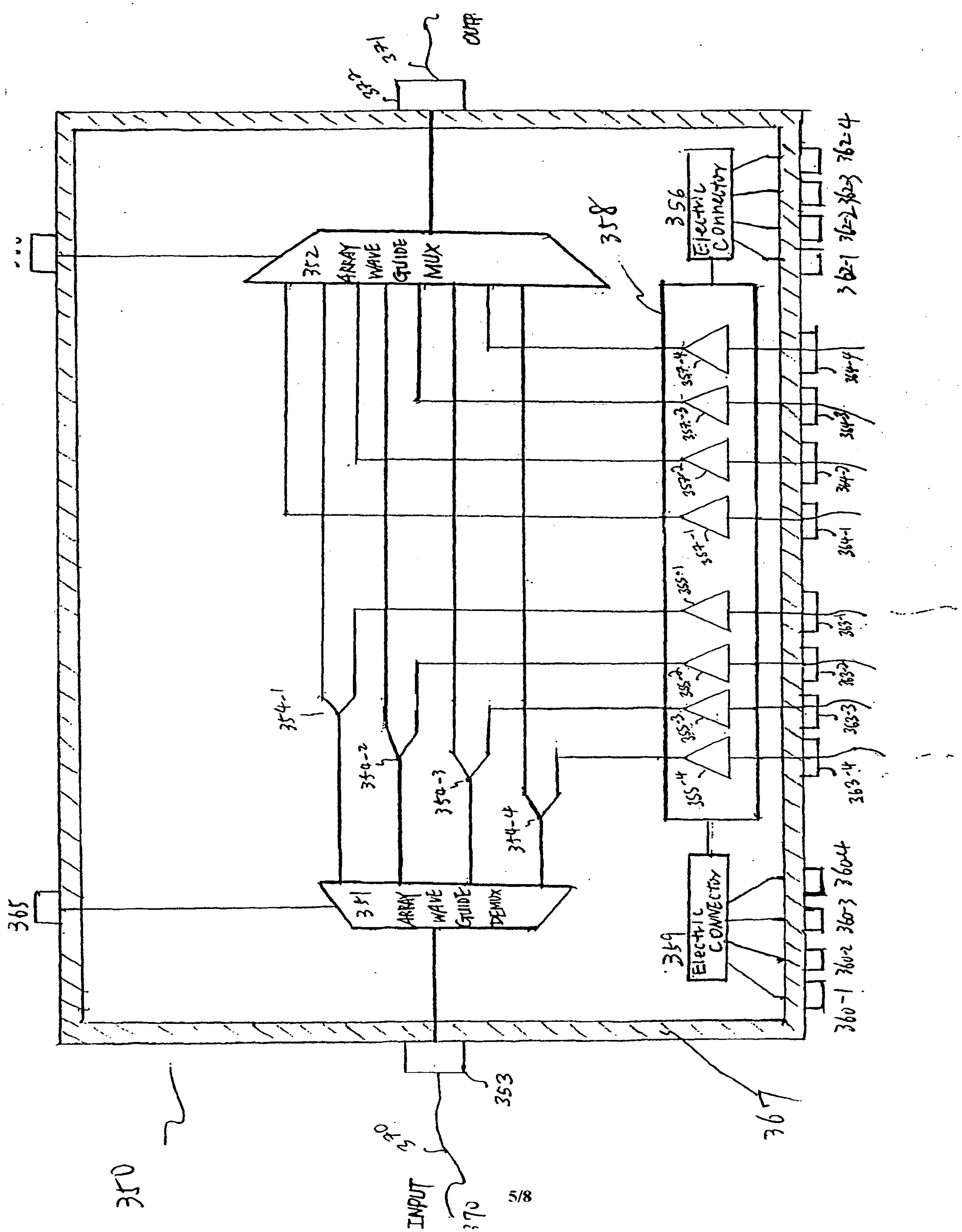

300
301
302
303 Demux
304 MUX
Add Controller
313
Drop Controller
308
Pass-Through Controller 310
Add 312
Drop 307

Figure 3a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351 ARRAY WAVE GUIDE DEMUX
356 Electric Connector
359 Electric Connector
INPUT
370
OUTP
371
372
353
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367
354-1
354-2
354-3
354-4
355-1
355-2
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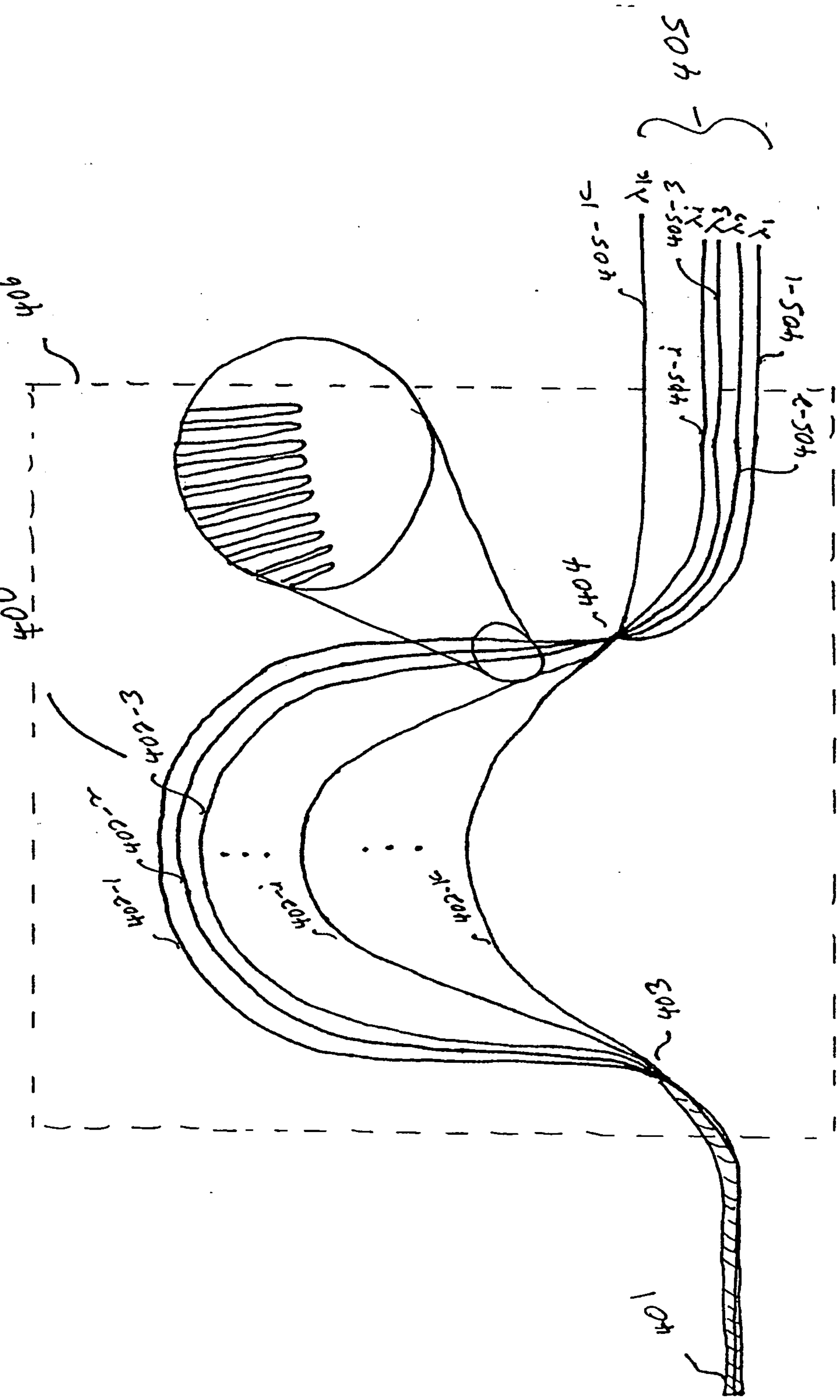
364-4


400
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403
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402-1
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405-1
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405-i
405-n

Figure 4

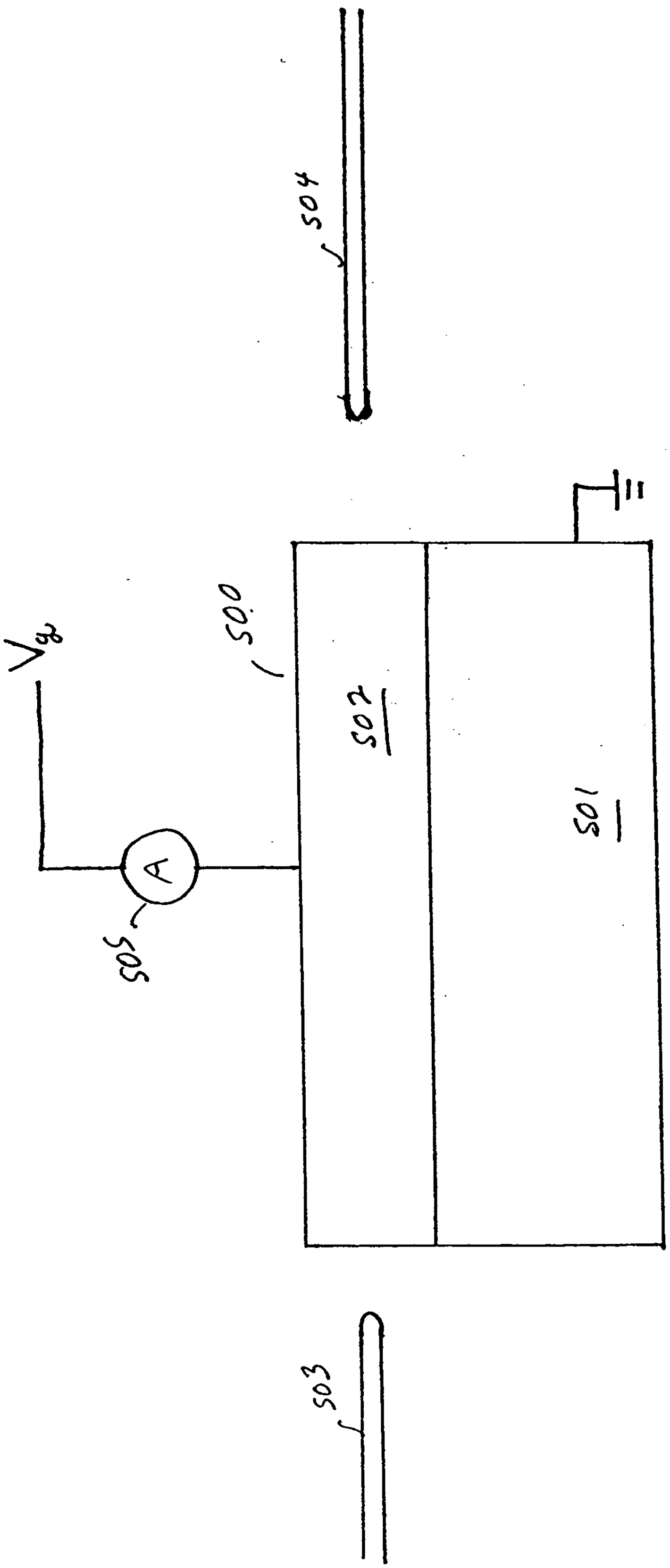
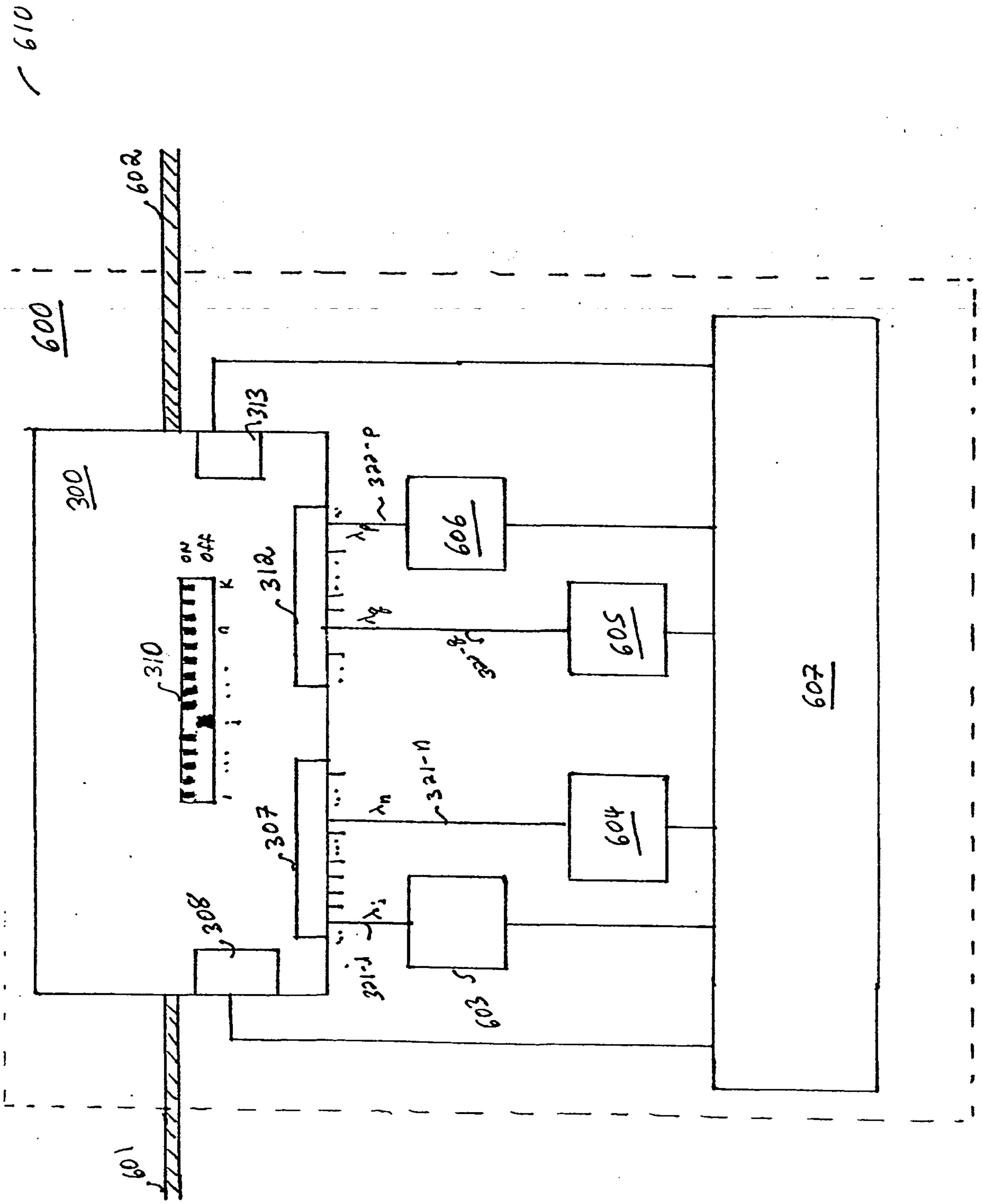


Figure 5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600
602
601
300
313
310
312
307
308
ON
OFF
K
λ_i
λ_n
λ_q
λ_p
321-i
321-n
322-q
322-p
603
604
605
606
607

Figure 6

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 01/04086

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04J14/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 43 37 089 A (SIEMENS AG) 4 May 1995 (1995-05-04) column 1, line 3 - line 33 column 3, line 55 -column 4, line 39; figure 2 --- -/--	1-29

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
4 July 2001	10/07/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Roldán Andrade, J

Application No
PCT/US 01/04086

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 11 027707 A (NEC) 29 January 1999 (1999-01-29) -& US 6 115 517 A (NEC) 5 September 2000 (2000-09-05) column 1, line 7 - line 10 column 6, line 22 -column 9, line 50; figures 1-4 column 10, line 62 -column 12, line 67; figures 5-7 column 13, line 24 -column 14, line 43; figure 8 column 16, line 21 -column 17, line 54; figure 12 column 19, line 27 -column 20, line 43 ---	1-29
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WO 9960740	A	25-11-1999	US	6233074	B	15-05-2001
			AU	3118999	A	06-12-1999

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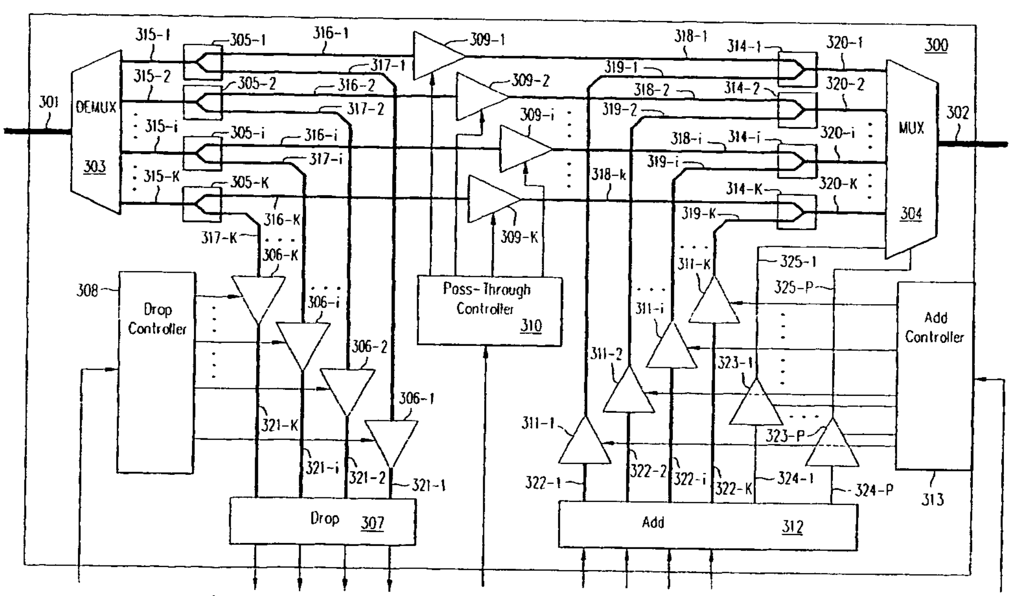

(57) Abstract: A dynamic programmable optical add/drop module for Dense Wavelength Division Multiplexed networking systems is presented. The optical add/drop module can be a drop module, an add module, or an add/drop module. Further, the optical add/drop module includes semiconductor optical amplifiers, allowing for programmability. Optical add/drop modules can selectively drop light beams of selected wavelengths. Furthermore, the optical add module can be programmed through semiconductor optical amplifiers to add data onto specific wavelengths. The optical add/drop module with semiconductor optical amplifiers has a fast switching speed and is highly versatile.

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DYNAMIC PROGRAMMABLE OPTICAL ADD/DROP MODULE

BACKGROUND

1. FIELD OF THE INVENTION

This invention relates to wavelength division multiplexed optical communication systems and, more particularly, to optical modules for adding or dropping optical signals on a wavelength division multiplexed optical network system.

2. DISCUSSION OF RELATED ART

Optical communications systems, and therefore the components of optical communications systems, are quickly being developed for high bandwidth optical data transmission. High bandwidth systems are in demand for telecommunications networks, metro-systems, local area networks, and cable television subscriber networks, for example.

In many networking systems, in order to transmit data from a plurality of sources to a plurality of receivers over a single medium, time-division multiplexing is employed. In time-division multiplexing, particular time slots are allotted to particular sources and a data signal from a single source is reconstructed by the receiver reading data from the appropriate time slots. The signal carrying capacity in time-division multiplexing on optical fibers is limited, however, by fiber dispersion and the need for high peak-power optical pulses.

The information carrying capacity of an optical fiber can be greatly enhanced using wavelength division multiplexing (WDM). In wavelength division multiplexing,

data signals are transmitted over an optical beam. The optical beam includes a plurality of light beams, each one of the plurality of light beams having light of a specified wavelength. A single fiber, therefore, can carry the optical beam with individual data signals on each of the plurality of light beams. In other words, data signals can be transmitted on different wavelengths of light through the optical fiber. Wavelength-division multiplexing can be combined with time-division multiplexing as well as other data transmission schemes (e.g., packet transmission) in order to transmit large volumes of data over the network at very high data transmission rates.

Most nodes on the network have the ability to receive signals directed to that node. When wavelength-division multiplexing is used, nodes typically receive signals from light of a subset of the available wavelengths propagating on the optical fiber. Nodes on the network, therefore, need the ability to "drop" one or more of the plurality of light beams so that data signals carried on those dropped light beams can be processed by node opto-electronics.

Additionally, at least one of the nodes on the network has the ability to couple signals onto the available light beams of individual wavelengths propagating on the optical fiber. These nodes, then, need to be able to "add" light of one or more of the different wavelengths to the corresponding one or more of the plurality of light beams.

Figure 2 shows a block diagram of an example conventional network node 210. Example node 210 receives optical signals from input fiber 211 and outputs optical signals to output fiber 212. Node 210 includes on optical unit 200. Although some embodiments of optical unit 200 can drop incoming light beams having multiple wavelengths, optical unit 200 drops light beams having wavelength λ_i and

adds for transmission optical signals having optical wavelength λ_i.

Optical detector 203 receives the light beam dropped by optical unit 200, the optical signal at wavelength λ_i thus dropped is further processed at node 201. Opto-electronic network 205 includes the computer systems, televisions, or other transmitter/receiver systems that utilize the data transmitted to node 210. In some cases, where node 210 transmits data as well as receives data, opto-electronic network 205 is coupled to optical source 204. Optical source 204 generates new optical signals in response to opto-electronic network 205. The new optical signals are transmitted on the carrier wavelength λ_i. The optical signal is added to the light beam of wavelength λ_i by optical unit 200.

Optical unit 200, as shown in Figure 2, includes demultiplexer 201 and multiplexer 202. Demultiplexer 201 receives input light beams from input fiber 211. Each of the input light beams includes light of one of the multiple wavelengths λ_1 through λ_K. Demultiplexer 201 spatially separates the input light beams according to their individual wavelengths.

Except for the light beam of wavelength λ_i, all of the input light beams from demultiplexer 201 are coupled to multiplexer 202. The light beam of wavelength λ_i is output from optical unit 200. Multiplexer 202 receives light of all wavelengths, including light of wavelength λ_i which is input to optical unit 200, and couples all of the light beams to output fiber 212. In some embodiments of add/drop modules such as add/drop unit 200, multiple input beams (each having a different wavelength) is dropped and multiple input beams are added. In some embodiments, input beams of different wavelengths are added than those that are dropped.

In some cases, all of the light beams on optical fiber 211 are dropped and opto-electronic network 205 detects the selected signals directed at it. Opto-electronic network 205 then arranges to add all of the data signals to output fiber 212. In that case, opto-electronic network 205 includes a significant amount of electronics and optical sources devoted to repeating optical signals that may not be utilized by node 210.

Conventionally, optical unit 200 is a fixed wavelength device, operating at a particular set of wavelengths $\{\lambda_i\}$, which is a subset of the wavelengths utilized by the network system. Problematically, optical add/drop 200 can not be easily reconfigured for other wavelengths. Additionally, optical add/drop 200 may include complicated, lossy, and expensive components such as optical circulators or micro-mechanical mirror arrays, creating additional expense and complication in an optical network system.

For example, U.S. Patent No. 5,982,518 to V. Mizrahi, issued Nov. 9, 1999, describes an optical add/drop that includes two optical circulators, two arrays of Bragg gratings, and an optical isolator. The optical add/drop described by Mizrahi is capable of coupling out of an incoming optical fiber multiple wavelengths of light, and coupling into the outgoing optical fiber multiple wavelengths of light. However, the wavelengths coupled out (or into) the optical add/drop are not themselves separated into individual wavelength light beams. Furthermore, Bragg grating arrays are temperature sensitive and therefore the wavelength of operation for such arrays may drift. Further, Bragg gratings are fixed wavelength devices. Also, the arrays of Bragg gratings themselves can not be easily changed. Therefore, the optical add/drop according to Mizrahi can not be

reconfigured or reprogrammed. Additionally, optical circulators are expensive and bulky devices.

Another optical add/drop device is described in U.S. Patent No. 5,960,133 to W. Tomlinson, issued Sep. 29, 1999. The optical add/drop device described by W. Tomlinson utilizes micromechanical mirrors in order to select particular wavelengths of light for coupling into or out of the optical add/drop device. Micromechanical mirrors provide the ability to select light beams of particular wavelengths from the array of wavelengths light on the optical fiber, thereby overcoming the problem of reconfiguring the system. However, production of micromechanical mirrors is complex and expensive. Additionally, the switching speeds of micromechanical mirrors is about several milliseconds and, therefore, is too slow for many applications. Additionally, devices with many movable parts (such as micromechanical mirrors) cause reliability problems.

Therefore, there is a need for versatile optical components, such as optical add and drop modules, that couple optical signals from an optical fiber to node opto-electronics and couple signals from the node opto-electronics onto the optical fiber.

SUMMARY

According to the present invention, a dynamic programmable optical unit is presented. Some embodiments can decouple ("drop") light from one or more of a plurality light beams carried by an input optical fiber. Some embodiments can couple ("add") light to one or more of a plurality of light beams on an output optical fiber. Each of the plurality of light beams includes light of a specified wavelength where the set of specified

wavelengths is predetermined for the networking environment that includes the dynamic optical unit.

Most embodiments of the dynamic optical unit are capable of dropping one or more of the plurality of light beams from the input optical fiber and adding to one or more of the plurality of light beams to the output optical fiber. In most embodiments, the ability to drop or add light beams is controllable either at the time of installation or during operation of the optical module. In some embodiments, the plurality of light beams from the input optical fiber is of a different set of predetermined wavelengths than the plurality of light beams to the output optical fiber.

One embodiment of the optical module includes a demutliplexor coupled to the input optical fiber to receive a plurality of light beams and at least one individually selectable optical amplifier coupled to the demultiplexer. Each of the at least one individually selectable optical amplifiers is coupled to receive at least a portion of light from one of the plurality of light beams. The at least one optical amplifier can provide programmable selectability to drop light of specific wavelengths from the light beams on the incoming optical fiber. The output beam from each of the at least one optical amplifier can be coupled to node opto-electronics outside of the optical module.

The optical amplifiers can function as gates, having an "on" or "off" state. Further, the optical amplifiers in the "on" state have a gain characteristic, amplifying the light beams incident on them. Further, in the "off" state, optical amplifiers provide excellent isolation, preventing the backward propagation of light.

In many embodiments, the optical amplifiers are semiconductor optical amplifiers. Semiconductor optical amplifiers have excellent switching times. Typical

switching times for semiconductor optical amplifiers are about 0.5 to 1 ns, a few orders of magnitude faster than currently available switching devices (such as mirror arrays), which operate in millisecond or microsecond time ranges.

Some embodiments further include a multiplexer that couples outgoing optical signals to one or more of a plurality of output light beams to be coupled to an output optical fiber. The output light beams may be coupled to the input light beams of the demultiplexer. Also, embodiments may include one or more individually selectable add optical amplifiers coupled to add light to one of the plurality of output light beams received by the multiplexer. The add optical amplifier can provide programmable selectability to add data signals to light beams of specific wavelengths on the outgoing optical fiber by switching the optical amplifier to an "on" or "off" state.

Yet other embodiments of the optical unit include a multiplexer that couples the plurality of output light beams to the optical fiber and at least one optical amplifier coupled between the node opto-electronics and the multiplexer. Optical data signals are added to one or more of the plurality of output light beams coupled to the optical fiber.

Additionally, some embodiments include at least one individually selectable optical amplifier coupled between a demultiplexer and a multiplexer, each of the at least one individually selectable optical amplifiers amplifying light from one of the plurality of input light beams and coupling an amplified beam to the multiplexer.

In some embodiments, multiple light beams may be coupled to a single optical amplifier. Semiconductor optical amplifiers typically have a wide enough band-width (about 70 to about 80 nm) to amplify more than one of the

wavelengths of light. In some instances, the band-width of a semiconductor optical amplifier can be tuned to accommodate several light beams.

In most embodiments, specific ones of the input light beams are selected for drop. Also, light of additional wavelengths can be added to the output light beams. Additionally, light of wavelengths corresponding to the input individual wavelength light beams that are dropped can also be added. Other embodiments of the invention, however, may independently receive and transmit signals on light of any of the available wavelengths on the input optical fiber and output optical fiber, respectively.

For example, in digital interactive television networks, data signals for each individual program may be delegated to one of the discreet wavelengths of light. Light of one wavelength may carry signals for multiple programming, where individual programming may be time-division multiplexed with other programming already carried on the light beams. A remaining number of light beams having selected discreet wavelengths of light may be dedicated to data communications between a consumer and a provider. The consumer, therefore, would select individual programming, at least in part, by selecting the wavelength of light that carries the data signal for that programming. Data is transmitted between the consumer and the provider on a light beam of a different wavelength.

In some embodiments of the invention, only one input light beam is selected for receipt and/or one individual wavelength of light is selected for addition at any given time. In other embodiments, multiple individual wavelength light beams may be selected at any given time.

Embodiments of the invention further include control opto-electronics that determines the gain or "on"/"off" state of each of the optical amplifiers. In some embodiments, the control opto-electronics includes

switches set by an installer so that the gain or "on"/"off" state of some or all of the optical amplifiers is set on installation. Some embodiments are externally controlled and set the characteristics of some or all of the optical amplifiers in response to control signals from the node opto-electronics.

These and other embodiments are further discussed below with respect to the following figures.

BRIEF DESCRIPTION OF THE FIGURES

Figure 1a shows an example of an optical network.

Figure 1b shows an example of another optical network.

Figure 2 shows a block diagram of a node included in the network of Figure 1.

Figure 3a shows a block diagram of an embodiment of an optical module according to the present invention.

Figure 3b shows a block diagram of another embodiment of an optical module according to the present invention.

Figure 4 shows a block diagram of a demultiplexer.

Figure 5 shows a block diagram of an optical amplifier.

Figure 6 shows a block diagram of an example node that includes a dynamic add/drop module according to the present invention.

In the figures, elements having the same or similar functions have the same designation.

DETAILED DESCRIPTION

Figure 1a shows an example optical network 100 having a plurality of nodes operating on a single fiber. Figure 1a shows, for example, a configuration of an optical loop

network 100 having nodes 101-1 through 101-N. Node 101-j designates an arbitrary one of nodes 101-1 through 101-N. Optical fiber 102 is a loop of optical fiber carrying light of multiple discreet wavelengths λ_1 through λ_K.

Wavelengths λ_1 through λ_K are typically part of a standard set of wavelengths preselected for transmitting data on network 100. An example of one such set of wavelengths recommended by the International Telecommunications Union (ITU) is given in Table 1. Sets of wavelengths having as many as 128 channels (individual wavelengths).

Table 1

Optical Channel	Central Wavelength (nm)	Central Frequency (THz)
λ_1	1548.51	193.6
λ_2	1549.32	193.5
λ_3	1550.12	193.4
λ_4	1550.92	193.3
λ_5	1551.72	193.2
λ_6	1552.52	193.1
λ_7	1553.33	193.0
λ_8	1554.13	192.9
λ_9	1554.94	192.8
λ_{10}	1555.75	192.7
λ_{11}	1556.55	192.6
λ_{12}	1557.36	192.5
λ_{13}	1558.17	192.4
λ_{14}	1558.98	192.3
λ_{15}	1559.79	192.2
λ_{16}	1560.61	192.1

Optical fiber 102 is shown as having sections 102-1 through 102-N. In many networks, each node 101-1 through 101-N is assigned a subset of the available multiple wavelengths, time slots on light beams of the individual wavelengths (i.e., each individual wavelength may be time division multiplexed as well as the entire scheme being wavelength division multiplexed), or addresses for packets sent on light beams of the individual wavelengths (i.e., packet transmission as well as wavelength division multiplexing). For example, in a video subscriber network each individual video program can be transmitted utilizing one light beam at a specified wavelength. With time-division multiplexing, multiple programs can be transmitted on each of the available light beams.

Some networks include more than one optical fiber for redundancy. Additionally, some networks are configure differently, such as hub and spoke networks or branching networks. Network 100 is shown as a circular loop for demonstration only. Most networks employ multiple fiber loops (not shown) for redundancy.

In Figure 1a, at least one of nodes 101-1 through 101-N has the ability to drop (i.e., read) one or more of the individual wavelengths of light from optical fiber 102. Additionally, at least one of nodes 101-1 through 101-N has the capability to add light of one or more of the individual wavelengths onto optical fiber 102. In most embodiments, each of nodes 101-1 through 101-N has the ability to read (i.e. drop) light beams of one or more of the individual wavelengths carried on optical fiber 102 and each of nodes 101-1 through 101-N has the ability to couple data signals into light of one or more of the wavelengths of light carried on optical fiber 102.

Figure 1b shows a broader optical network 150. Optical network 150 includes a long-haul network 151, a metro network 152, and an access network 153. Long-haul

network 151, metro network 152 and access network 153 are all examples of circular networks. Long-haul network 151 includes nodes 151-1 through 151-L coupled by optical fibers 155. Optical fibers 155 carry a plurality of light beams, each of the plurality of light beams having a predetermined wavelength from a set of wavelengths for the long-haul network environment.

Node 151-i, which is one of nodes 151-1 through 151-L, is also a member of metro network 152. Metro network 152 further includes nodes 152-2 through 152-M. The nodes of metro network 152 are coupled by optical fibers 156. Optical fibers 156 carry a plurality of light beams, each of the plurality of light beams having a predetermined wavelength from a set of wavelengths for the metro network environment, which may be different from the set of wavelengths for the long-haul network environment.

Node 152-j, which is one of nodes 152-2 through 152-M, is also a member of access network 153. Access network 153 further includes nodes 153-2 through 153-N. The nodes of access network 153 are coupled by optical fibers 157. Optical fibers 157 carry a plurality of light beams, each of the plurality of light beams having a predetermined wavelength from a set of wavelengths for the access network environment, which may be different from the set of wavelengths for the long-haul network environment. Node 153-k, which is one of nodes 153-2 through 153-N, is a hub of hub and spoke network 154. Network 154 includes nodes 154-1 through 154-O, all coupled to node 153-k through optical fibers carrying a plurality of light beams. Each of the plurality of light beams has a predetermined wavelength from a set of wavelengths for the network environment of network 154, which may be a different set of wavelengths from that of networks 151, 152 or 153.

Any of the nodes in networks 151, 152 or 153 may be as shown in Figure 2. However, at least one of the nodes in a network according to the present invention includes an optical device such as optical device 300 of Figure 3a. Figure 3a shows a dynamic optical device 300 according to the present invention. Optical device 300 is extremely versatile. Additionally, many embodiments of optical device 300 are programmable.

Optical device 300, as shown in Figure 3a, includes a demultiplexer 303 and a multiplexer 304. Other embodiments may include only one of demultiplexer 303 or multiplexer 304. Demultiplexer 303 is coupled to receive light carried on input fiber 301. Input fiber 301 carries data signals on a plurality of light beams, each of the plurality of light beams having one of a set of distinct wavelengths λ_1 through λ_K. The set of distinct wavelengths λ_1 through λ_K is the set of wavelengths chosen for utilization on the optical network environment of input fiber 301. An arbitrary one of wavelengths λ_1 through λ_K is designated λ_i. The set of distinct wavelengths can include any number of individual wavelengths. In most embodiments, the set of wavelengths λ_1 through λ_K is determined by an industry standards, such as the ITU, for that networking environment.

Data signals can be modulated in any fashion on the light beams. Additionally, data can be encoded in any fashion. Data can be encoded in any manner and transmitted in a time-division multiplexed mode on the discreet wavelengths of light, by burst packet transmission on the discreet wavelengths, or by any other fashion. Some common types of modulators for use in optical systems include lithium niobate ($LiNbO_3$) Mach-Zhender (MZ) modulators, indium phosphide (InP) Mach-

Zhender modulators, and indium phosphide (InP) electro-absorption (EA) modulators.

Demultiplexer 303 can be any device which is capable of spatially separating the input light beams, each of the input light beams having light of one of discreet wavelengths λ_1 through λ_K. An example of a phasar device utilized as a demultiplexer is shown in Figure 4. Phasar device 400 is compact and integrable into an optical circuit or a silicon optical bench (SiOB). Other examples of demultiplexers include the use of thin-film filters.

In most embodiments of the invention, demultiplexer 303 (Figure 3a) couples the light beams of each of the discreet wavelengths λ_1 through λ_K into a corresponding optical fiber 315-1 through 315-K. Each of the optical fibers 315-1 through 315-K can be coupled to a corresponding one of intensity splitters 305-1 through 305-K. Optical fiber 315-i in Figure 3a, for example, is coupled to intensity splitter 305-i. Intensity splitter 305-i splits the light beam of wavelength λ_i into two output beams and couples one beam into optical fiber 316-i and a second beam into optical fiber 317-i. In general, each of intensity splitters 305-1 through 305-K splits its input beam into two or more output beams, coupling a first output beam into optical fibers 316-1 through 316-K, respectively, and a second output beam into optical fibers 317-1 through 317-K, respectively. In some embodiments, each of intensity splitters 305-1 through 305-K can split its corresponding input beam into more than two beams and couple each of the beams into a separate optical fiber.

Intensity splitters 305-1 through 305-K can each be arranged to split the intensity of its corresponding input beam in any fashion between its two or more output beams. In many embodiments of the invention, for example, about 90% of the intensity of the light beam from optical fiber 315-i that is coupled to intensity splitter 305-i is

coupled to optical fiber 316-i and about 10% is coupled to optical fiber 317-i. Other embodiments can use any splitting of intensities. Further, some embodiments of the invention may have different intensity on each of intensity splitters 305-1 through 305-K, depending on particular applications of optical module 300.

Optical fibers 316-1 through 316-K can each be coupled to a corresponding one of optical amplifiers 309-1 through 309-K. In most embodiments, each of optical amplifiers 309-1 through 309-K are semiconductor optical amplifiers. Figure 5 shows a block diagram of a multiple quantum-well semiconductor optical amplifier that can be utilized as optical amplifiers 309-1 through 309-K.

Each of optical amplifiers 309-1 through 309-K is coupled to receive a corresponding light beam of wavelength λ_1 through λ_K, respectively, from the corresponding optical fibers 316-1 through 316-K, respectively. Optical amplifiers 309-1 through 309-K optically amplify the input light beam and couple the resulting light beam to a corresponding one of optical fibers 318-1 through 318-K. Optical fibers 318-1 through 318-K can be coupled to intensity splitters 314-1 through 314-K, respectively.

Intensity splitters 314-1 through 314-K combine each of the light beams from optical fibers 318-1 through 318-K with a light beam from a corresponding one of optical fibers 319-1 through 319-K and couples the resulting light beam to a corresponding one of optical fibers 320-1 through 320-K. Added signals to the output beam are input through optical fibers 319-1 through 319-K, where new data transmitted on light of wavelength λ_i to the optical network through add/drop module 300 is input through optical fiber 319-i to intensity splitter 314-i. Each of optical fibers 320-1 through 320-K, carrying data signals at wavelengths of λ_1 through λ_K respectively, is input to

multiplexer 304. Multiplexer 304 couples the light beams from each of optical fibers 320-1 through 320-K into output fiber 302.

In some embodiments, multiplexer 304 couples to a fiber in a networking environment having a different subset of wavelengths λ_1' through λ_P', where P is the number of available wavelenths in the networking environment that includes fiber 302. In that case, light beams of wavelength other than the set of wavelengths received is added at mutliplexer 304. In Figure 3a, add 312 is further optically coupled to optical amplifiers 323-1 through 323-P. Optical amplifiers 323-1 through 323-P are optically coupled to add 312 through fibers 324-1 through 324-P, respectively, and optically coupled to multiplexer 304 through optical fibers 325-1 through 325-P, respectively. Optical amplifiers 323-1 through 323-P are further coupled to add controller 313. Through optical amplifiers 323-1 through 323-P, optical device 300 can add light beams of wavelengths λ_1' through λ_P' to optical fiber 302.

In some embodiments, multiplexer 304 may be coupled directly to optical fibers 318-1 through 318-K and 319-1 through 319-K, relieving the need for separate intensity splitters 314-1 through 314-K.

Multiplexer 304 may be a phasar multiplexer, which is shown in Figure 4, or may be constructed similarly to an intensity splitter such as splitter 314-1 through 314-K arranged for combination of light beams. In some embodiments, intensity splitters 314-1 through 314-K combine the two input beams in a 1:1 ratio, other embodiments may utilize different mixing ratios. If multiplexer 304 is a phasar device, then intensity splitters 314-1 through 314-K are likely necessary to combine all light of each wavelength into a single input beam for each wavelength to multiplexer 304.

In many embodiments, for fewar than about 16 channels (i.e., K is less than about 16), intensity splitter 314-1 through 314-K can be reverse splitters. For more than about 16 channels, other phasar devices such as a phasar multiplexer (as shown in Figure 4) or a thin-film multiplexer can be utilized. In many embodiments, intensity splitters 314-1 through 314-K are arranged for a 50/50 combination and light beams are either on fibers 318 or on fibers 319, but not both.

Optical amplifiers 309-1 through 309-K are each electrically coupled to pass-through controller 310. Pass-through controller 310 controls the gain of each of optical fibers 309-1 through 309-K. In most embodiments, pass-through controller 310 can be controlled from outside of add/drop module 300. In some embodiments, pass-through controller 310 can be externally programmed to set the gain on each of optical amplifiers 309-1 through 309-K. Due to the speed of switching of solid state optical amplifiers, i.e. about one nanosecond, optical device 300 can provide fast device reconfiguration.

In some embodiments, pass-through controller 310 is preset or can be preset (e.g., via dip-switches or patch wires) to independently control the gain of each of optical amplifiers 309-1 through 309-K at the time of installation of add/drop module 300 into a network system.

In most embodiments, the gains of optical amplifiers 309-1 through 309-K are arranged to offset the loss of intensity of the pass-through light beam in add/drop module 300. The gain may also be set to offset the loss of intensity in optical fiber 301 (i.e., optical amplifiers 309-1 through 309-K may function as signal boosters).

In some instances, the gain of optical amplifiers 309-1 through 309-K can be dynamically set so that the intensity of each wavelength of output beam from add/drop

module 300 is a constant (i.e., the intensity of the output beam on optical fiber 318-i is related to the intensity of the light beam on optical fiber 319-i so that the combination of the two produces a beam with constant average intensity).

In some cases, one or more of optical amplifiers 309-1 through 309-K can be set to 0 in order to provide a beam-block to through signals. For example, in optical ring network 100 (Figure 1) individual packets of data need to be removed completely from optical fiber 102. If individual packets are not removed after they are transmitted, they will continue to circulate (being amplified by optical amplifiers in each of nodes 101-1 through 101-N) and contribute to unwanted noise or otherwise interfere with further transmission of data on optical fiber 102.

Light beams from optical fibers 317-1 through 317-K can be coupled into a corresponding one of optical amplifiers 306-1 through 306-K. The light beam of wavelength λ_i carried on optical fiber 317-i is coupled into optical amplifier 306-i, for example. Optical amplifiers 306-1 through 306-K each amplify the light beam from the corresponding optical fiber 317-1 through 317-K and couples the amplified light beam to a corresponding one of optical fibers 321-1 through 321-K. Drop controller 308 is electrically coupled to each of optical amplifiers 306-1 through 306-K in order to independently control the gain of optical amplifiers 306-1 through 306-K. In many embodiments, the gain of optical amplifiers 306-1 through 306-K is predetermined and drop controller 308 switches the state of each of optical amplifiers 306-1 through 306-K between an "on" state and an "off" state.

In some embodiments of the invention, drop controller 308 is externally programmable to turn on (the "on" state) or off (the "off" state) one or more of optical amplifiers

306-1 through 306-K. The gain of the one or more of optical amplifiers 306-1 through 306-K that is turned on can be predetermined, set on installation (e.g., through dip switches or on-board jumper wires), or externally programmed. In some embodiments, drop controller 308 includes installer setable switches (e.g., dip switches) to separately set the gain of each of optical amplifiers 306-1 through 306-K. Further, in other embodiments drop controller 308 is preset to control the gains of each of optical amplifiers 306-1 through 306-K.

Optical fibers 321-1 through 321-K, carrying the output beams from optical amplifiers 306-1 through 306-K, is shown coupled to drop module 307. Drop module 307 represents the output coupler, coupling the selected data signals from add/drop module 300. In some embodiments, optical fibers 321-1 through 321-K are output directly from add/drop module 300. In that case, the drop output signals from add/drop module 300 is carried optically on optical fibers 321-1 through 321-K. In other embodiments, drop module 307 multiplexes the light beams from optical fibers 321-1 through 321-K into one or more output optical fibers. In yet another embodiment of the invention, drop 307 includes one or more optical detectors in order to convert the data signals carried by the light beams on optical fibers 321-1 through 321-K into output electrical signals. In most such embodiments, each optical fiber 321-1 through 321-K is coupled to a single detector so that the detector can be optimized for detection of that wavelength.

Some embodiments include the ability to add optical signals to one or more of the output light beams. In Figure 3a, add module 312 receives signals into optical module 300 that are to be transmitted on output optical fiber 302. In some embodiments, add module 312 may be optical couplers so that data input signals to optical

module 300 are optical. In that case, add module 312 couples optical fibers 322-1 through 322-K directly out of optical module 300 so that optical fibers 322-1 through 322-K receive data signals on light of wavelengths λ_1 through λ_K, respectively.

In other embodiments, add module 312 receives electrical signals, including data signals to be transmitted as optical signals. In that case, add module 312 includes one or more light sources (e.g., lasers) which can be tuned to each of wavelengths λ_1 through λ_K and appropriately coupled to optical fibers 322-1 through 322-K. In most such embodiments, add module 312 includes a separate laser for each of wavelengths λ_1 through λ_K coupled to optical fibers 322-1 through 322-K, separately. Each of the separate lasers may be modulated to transmit the data received on the electrical input lines. Other embodiments modulate the light beams in other ways, for example by modulating the gain of the appropriate one of optical amplifiers 311-1 through 311-K, in order to place data signals on the light beams. Further, add module 312 may be programmable to independently address the light source to each of optical fibers 322-1 through 322-K and direct input data to the appropriate light source for transmission at a particular wavelength λ_i.

Optical fibers 322-1 through 322-K are coupled to optical amplifiers 311-1 through 311-K, respectively. Optical amplifiers 311-1 through 311-K are further coupled to intensity splitters 314-1 through 314-K, respectively, in order to insert optical data onto output optical fiber 302. The gains of optical amplifiers 311-1 through 311-K are controlled by add controller 313.

In some embodiments, add controller 313 is externally programmed to set the gains of optical amplifiers 311-1 through 311-K. In some cases, add controller 313 is

externally programmed to turn on one or more of optical amplifiers 311-1 through 311-K to a preset gain level. The preset gain level, in some embodiments, can be set by an installer (e.g., by setting dip switches). Add controller 313 is preset to set the gain of one or more of optical amplifiers 311-1 through 311-K. In most embodiments, add controller 313 cooperates with add module 312 so that add module 312 outputs light beams to one or more of optical amplifiers 311-1 through 311-K that are activated (e.g., placed in the "on" state) by add controller 313.

In one embodiment of the invention, optical module 300 is constructed on a single semiconductor chip. Demultiplexers, multiplexers, optical amplifiers, and intensity splitters can all be implemented on a single integrated optical circuit. Further, the optical fibers can be replaced by waveguides constructed on the integrated circuit. Further, control circuitry can also be constructed on the semiconductor chip.

Figure 3a shows an example embodiment where fiber 301 and fiber 302 can both carry light beams having wavelengths λ_1 through λ_K. In addition, optical fiber 302 can also carry wavelengths λ_1' through λ_P'. In some embodiments, optical module 300 receives light beams of a set of wavelengths λ_1 through λ_K from optical fiber 301 and is coupled to optical fiber 302 which carries a different set of wavelengths λ_1' through λ_P'. In that case, light beams dropped by optical device 300 and added by optical device 300 may be of differing wavelengths. In one particular embodiment, optical device 300 receives only a subset of light beams of the available wavelengths and adds light beams, still within the original set of wavelengths, but different from those actually received. In that case, not all of optical fibers 315-1 through 315-K are present in optical device 300.

Figure 3a shows an embodiment of an add/drop optical module that both drops optical signals and adds optical signals to the network system. Other embodiments of the invention may only drop or only add optical signals. One embodiment, for example, includes only demultiplexer 303 and at least one of optical amplifiers 306-1 through 306-K. Another embodiment includes only multiplexer 304 and at least one of optical amplifiers 311-1 through 311-K. Other embodiments may include one or more of intensity splitters 305-1 through 305-K, intensity splitters 314-1 through 314-K, or optical amplifiers 309-1 through 309-K. One skilled in the art will recognize numerous configurations of optical devices according to the present invention, each of which is intended to be within the scope of this disclosure.

Figure 3b shows a block diagram of a specific example of an embodiment of an optical module 350 according to the present invention. Optical module 350 receives signals from input optical fiber 370 and couples signals to output fiber 371. Optical module 350 includes 4-channel demultiplexer 351, 8-channel multiplexer 352, 1X2 splitters 354-1 through 354-4, and amplifier block 358. Amplifier block 358 includes optical amplfiers 355-1 through 355-4 and optical amplifiers 357-1 through 357-4. Optical module 350 is mounted within casing 367. Casing 367 can be any material that encloses optical module 350.

Demultiplexer 351 is coupled to input port 353 to receive light beams from input fiber 370. Input fiber 370 carries four light beams having wavelenghts λ_1 through λ_4, respectively. Demultiplexer 351 spatially separates the four light beams, which are then coupled into 1X2 splitters 354-1 through 354-4. Splitters 354-1 through 354-4 each split one of the four light beams into a first beam and a second beam. The first beam of each of splitters 354-1 through 354-4 is coupled into optical

amplifier 355-1 through 355-4, respectively. The output signals from optical amplifiers 355-1 through 355-4 are coupled to output ports 363-1 through 363-4, respectively, thereby dropping each of the the four light beams.

The second beam from each of splitters 354-1 through 354-4 are coupled into 8-channel multiplexer 352. Further, optical amplifers 357-1 through 357-4 are coupled to add input ports 364-1 through 364-4, respectively, to receive new light beams to be added to output optical fiber 371. The new light beams, in some embodiments, may each be of different wavelengths than the set of wavelengths λ_1 through λ_4 of the light beams carried by input optical fiber 370. The output signals from optical amplifiers 357-1 through 357-4 are coupled into multiplexer 352. The output signal from multiplexer 352 is coupled through output port 372 to output optical fiber 371.

In most embodiments optical amplifiers 355-1 through 355-4, 356-1 through 356-4, and 357-1 through 357-4 have either an "on" state or an "off" state. Optical amplifiers 355-1 through 355-4 are coupled through connector 359 to control ports 360-1 through 360-4 and optical amplifiers 357-1 through 357-4 are connected through connector 356 to control ports 362-1 through 362-4. Each of optical amplifiers 355-1 through 355-4 and 357-1 through 357-4 can be controlled by signals at connectors 360-1 through 360-4 and 362-1 through 362-4, respectively. Therefore, optical module 350 is dynamically programmable.

Demultiplexer 351 and multiplexer 352 each further includes a heater element. Demultiplexer 351 is coupled to heater ports 365 to receive heater power and multiplexer 352 is coupled to heater ports 366 to receive heater power.

Figure 4 shows a diagram of a phase device 400. Phase device 400 is either a multiplexer or a demultiplexer, depending on the direction of light propagation through the device. In demultiplexer operation, light having multiple wavelengths enters free propagation region 403 from optical fiber 401. Optical fiber 401 can carry a light beam of discreet wavelengths λ_1 through λ_K, with λ_i being an arbitrary one of the wavelengths. As has been previously discussed, in wavelength-division multiplexing the discreet wavelengths λ_1 through λ_K are preselected to be compatible with the network system. Phasar device 400 includes waveguide array 402-1 through 402-K that is matched to the discreet wavelengths λ_1 through λ_K.

Phase device 400 can be constructed on, for example, a silicon wafer. Additionally, phase device 400 may include a heater element 406 in order to avoid temperature affects in the performance of phase device 400. In many embodiments, heater element 406 holds the temperature of phase device 400 to about 70° C.

The beam of light entering the free propagation region 403 diverges and is coupled into waveguide array 402-1 through 402-K. The length of each waveguide in waveguide array 402-1 through 402-K is chosen such that the optical path length difference between adjacent waveguides equals an integer multiple of the central wavelength of phasar device 400. For the central wavelength, therefore, the electromagnetic fields of the light beams in waveguides 402-1 through 402-K will arrive at an output aperture 404 with phase differences of integer multiples of 2π. These fields, therefore, add constructively, reproducing the field distribution for the central wavelength light that is incident at the input of free propagation 403 at output aperture 404. This

reconstructed beam can be coupled to an individual optical fiber output 405.

Optical beams of other wavelengths will constructively interfere at other points on output aperture 404 corresponding to points were optical path differences along the waveguide array 402 for that wavelength of light corresponds to phase differences for that wavelength of multiple integers of 2π. Each of the separate beams propagates along a different path can be coupled into one of optical fibers 405 so that each of discreet wavelengths λ_1 through λ_K is coupled to one of optical fibers 405-1 through 405-K, respectively.

Phasar device 400, with input from optical fibers 405, can also operate as a multiplexer. Light of individual wavelengths λ_1 through λ_K from optical fibers 405-1 through 405-K, respectively, is coupled into phasar device 400 at aperture 404 and is coupled to optical fiber 401 at free propagation region 403. Phasar based demultiplexer are further discussed in M. Smit, "PHASAR-Based WDM-Devices: Principles, Design and Applications," IEEE J. of Selected Topics In Quantum Electronics, Vol. 2, No. 2, p. 236-250. However, for K less than about 16, it may be simpler to utilize reversed intensity splitters to provide a multiplexing function.

Figure 5 shows an example of a semiconductor optical amplifier 500. Optical amplifier 500 includes a substrate 501 and an active region 502. In most cases, the active region is InGaAs based technology. Optical amplifier 500 is coupled to an input optical fiber 503 and an output optical fiber 504.

Optical amplifier 500 is coupled to a voltage source V_g in active region 502 and a ground at substrate 501. If unpowered, active region 502 absorbs incident light. When a voltage is supplied at V_g, then charge carriers in active region 502 are promoted to higher energy levels. Photons

incident on active region 502, instead of being absorbed, initiate transitions from the higher energy levels into lower levels and the production of further photons, as in a laser device. Therefore, the amount of amplification (i.e., the number of photons emitted by active region 502 for each photon incident on active region 502) is dependent on the number of electrons held in the excited state, which depends on the current and voltage supplied at V_g.

If light is incident on active region 502 from optical fiber 503, light is emitted from active region 502 and coupled into optical fiber 504. The gain of amplifier 500 is determined by an input signal at V_g. In many instances, optical amplifier 500 has an "on" state when V_g is above a threshold level and an "off" state when V_g is below the threshold level.

In some cases, a current source 505 is provided to add current to amplifier 500, turning SOA 505 "on" or "off." For example, in a typical SOA a current of 40 mA may turn the SOA on with a gain of 5 dB at 1550 nm and 2.5 dB at 1530 nm. The SOA may saturate at 100 mA, providing a gain of 0 dB at 1530 nm and 5 dB at 1550 nm.

Semiconductor optical amplifiers (SOAs) have several advantageous properties. SOAs are fast switching (on the order of about 0.5 to about 1 ns), making them very attractive for dynamic, programmable optical systems requiring fast switching times. Additionally, SOAs are easlity integrated with other photonic devices in a planar waveguide.

The substitute of conventional bulk InGaAsP gain regions with multiple quantum well (MQW) technologies yields further advantages for SOAs. For example, the saturation output power is enhanced, allowing for high gains. MQW-SOAs typically have a broad-band gain spectrum, allowing for amplification over a broad range of

wavelengths (about 70 to 80 nm in some cases). MQW-SOAs further yield low noise figures, approaching the quantum limit. Polarization sensitivity of the MQW-SOA can be overcome successfully by employing both tensile and compressively strained quantum wells in a single active layer. Further advantages for utilizing multiple quantum well semiconductor optical amplifiers include their reliability, linearity of their amplification with signal input power, and reliable threshold current densities.

One skilled in the art is familiar with the use and operation of such semiconductor optical amplifiers. A further discussion of such optical amplifiers and the operation of such optical amplifiers is given in This, et al., "Progress in Long-Wavelength Strained-Layer InGaAs(P) Quantum-Well Semiconductor Lasers and Amplifiers," IEEE J. Quantum Elect., Vol. 30, No. 2, p. 477-499 (Feb., 1994), herein incorporated by reference in its entirety.

Figure 6 shows a block diagram of an add/drop module 300 according to the present invention in a node 600 of an optical network 610. Optical network 610 of which node 600 is a member can be ring network, as shown in Figure 1, or any other configuration of network. Input light beams having discreet wavelengths λ_1 through λ_K, each of which can be modulated to carry data signals, are transmitted on input optical fiber 601. Input optical fiber 601 is coupled to add/drop module 300. Output light beams having discreet wavelengths λ_1 through λ_K, carrying data signals, are coupled out of add/drop module 600 to output optical fiber 602.

In the embodiment of add/drop module 300 shown in Figure 6, pass-through controller 310 (Figure 3a) is a series of switches (e.g., a dip switch) which are set by an installer to provide a predetermined gain signal to each of optical amplifiers 309-1 through 309-K. In node 600, pass-through controller 310 is set to pass all of the

light beams except for the light beam having wavelength λ_i. In other words, the gains of all of optical amplifiers 309-1 through 309-K except for optical amplifier 309-i are set to amplify light. Amplifier 309-i is off and therefore acts as a beam block.

Drop controller 308 is externally programmed by node opto-electronics 607 to selectively turn on one or both of optical amplifiers 305-i and 305-n, thereby selecting one or both light beams of wavelengths λ_i and λ_n to drop. All of the remaining optical amplifiers are off. In the example shown in Figure 6, then, none of the light beams except for the light beams of wavelengths λ_i and λ_n are dropped at node 600. In other applications, such as for subscriber television networks for example, node opto-electronics 607 can selectively direct drop controller 308 to activate any one or more of optical amplifiers 305-1 through 305-K in order that node 600 can receive data carried by any one of the available light beams.

In the embodiment shown in Figure 6, only light beams of wavelength λ_i and λ_n are dropped. Drop module 307 is an optical coupler for all K of optical fibers 321-1 through 321-K, but in the application shown in Figure 6 only optical fibers 321-i and 321-n (Figure 3) are coupled out of add/drop module 300, through drop module 307. The remaining ones of optical fibers 321-1 through 321-K are not utilized.

Optical fiber 321-i is coupled to optical detector 603 and optical fiber 321-n is coupled to optical detector 604. Therefore, optical detector 603 receives light of wavelength λ_i and optical detector 604 receives light of wavelength λ_n. The electrical data signal from optical detectors 603 and 604 is received by node opto-electronics 607.

Node opto-electronics 607 can output optical signals for addition to output optical fiber 602 as well. In node 600 of Figure 6, node opto-electronics 607 outputs data signals to optical source 605 and optical source 606. Optical source 605 outputs light, modulated to carry the data signal transmitted to it, of wavelength λ_q and optical source 606 outputs light, modulated to carry the data signal transmitted to it, of wavelength λ_p. Optical source 605 is coupled, through add module 312, to optical fiber 322-q and optical source 606 is coupled to optical fiber 322-p. Each of optical fibers 322-q and 322-p are one of optical fibers 322-1 through 322-K of add/drop module 300. Node opto-electronics further outputs control signals to add controller 313 so that optical amplifiers 311-q and 311-p are turned on when there is data to transmit on light of wavelengths λ_q and λ_p, respectively. Add controller 313 of add/drop module 300 in node 600 is arranged such that all of the remaining optical amplifiers 311-1 through 311-K are off, allowing no light input to multiplexer 304 from add module 312.

In some embodiments of add/drop module 300, optical detectors 603 and 604 are included into drop module 307. Further, light sources 605 and 606 can be included in add module 312. Further, add/drop module 300 can be utilized with a wave-length division multiplexing scheme having any number of discreet wavelengths and any data modulation scheme.

The above described embodiments are demonstrative only. One skilled in the art will recognize numerous obvious variations, which are considered to be within the scope of this disclosure. As such, the invention is limited only by the following claims.

CLAIMS

I claim:

1. An optical module, comprising:

a demultiplexer coupled to an input fiber to receive a plurality of input light beams, each of the plurality of input light beams having a discrete wavelength of light;

at least one drop optical amplifier coupled to the demultiplexer to receive at least a portion of one of the plurality of input light beams; and

a drop module coupled to receive an output light beam from each of the at least one optical amplifier and provide a signal external to the module.

2. The module of Claim 1, wherein the demultiplexer is a phasar device.

3. The module of Claim 1, further including a drop controller coupled to control the at least one drop optical amplifier.

4. The module of Claim 3, wherein the at least one drop optical amplifier has an on state and an off state.

5. The module of Claim 1, wherein the at least one drop optical amplifier is a multiple quantum well solid state amplifier.

6. The module of Claim 1, further including a multiplexer that couples a second plurality of output light beams to an output fiber.

7. The module of Claim 6, wherein at least one of the second plurality of output light beams is coupled to one of the plurality of input light beams.

8. The module of Claim 7, further including at least one intensity splitter, the at least one intensity splitter coupled to receive one of the plurality of input light beams and split it into a first beam and a second beam, the first beam being coupled to one of the second plurality of output light beams and the second beam being coupled to one of the at least one drop optical amplifiers.

9. The module of Claim 7, wherein a booster optical amplifier is coupled between each of the at least one of the plurality of output light beams and the corresponding one of the plurality of input light beams.

10. The module of Claim 7, further including a pass-through controller controlling the gain of the booster optical amplifier.

11. The module of Claim 7, further including at least one output intensity splitter, each of the at least one output intensity splitter coupled to receive a first beam and a second beam and to output one of the second plurality of output light beams, the first beam coupled to receive one of the plurality of input light beams, and the second beam coupled to receive light from one of a plurality of add optical amplifiers.

12. The module of Claim 6, further including at least one add optical amplifier coupled each coupled to receive an output beam and coupled to one of the at

least one of the second plurality of output light beams.

13. The module of Claim 12, wherein the at least one add optical amplifier is a multiple quantum well solid-state amplifier.

14. An optical module, comprising:

a multiplexer coupled to an output fiber to transmit a plurality of output light beams, each of the plurality of output light beams having a discrete wavelength of light;

at least one add optical amplifier coupled to the multiplexer to add light to at least one of the plurality of the input light beams; and

an add module coupled to receive data signals and provide a light beam to each of the at least one add optical amplifier.

15. The module of Claim 14, wherein the multiplexer is a phasar device.

16. The module of Claim 14 wherein the at least one add optical amplifier is a multiple quantum well solid state optical amplifier.

17. The module of Claim 14, further including an add controller coupled to control the at least one add optical amplifier.

18. The module of Claim 17, wherein the gain settings for each of the at least one add optical amplifiers is set in response to external control signals.

19. A method of dropping data from an optical network, comprising:

demultiplexing light from an input fiber to obtain a spatially separated array of light beams, each of the array of light beams an individual wavelength; and

controllably amplifying a portion of at least some of the plurality of light beams.

20. The method of Claim 19, further including multiplexing output light beams to an output fiber.

21. The method of Claim 20, further including controllably amplifying a portion of at least one of the input light beams to form a corresponding at least one of the output light beams.

22. The method of Claim 19, further including splitting at least one of the input light beams into a first beam and a second beam, the first beam being coupled to a corresponding one of the output light beams, the second light beam being coupled to a corresponding one of the at least one drop optical amplifier.

23. A method of adding optical data to an optical network, comprising:

amplifying at least one optical light beam to form an output light beam having one of a set of discreet wavelengths, and

multiplexing the output light beam with at least one other output light beam to coupled the output light beam to an output fiber.

24. A network node, comprising:

a dynamic optical module coupled to receive an input light beam from the network and coupled to transmit an

output light beam to the network, the dynamic optical module including setable gain controls for at least one optical amplifier;

a node opto-electronics coupled to receive signals from the dynamic optical add/drop module and transmit data signals to the dynamic optical add/drop module.

25. The node of Claim 24, wherein the gain controls include controls for optical amplifiers for dropping light beams from the network.

26. The node of Claim 24, wherein the gain controls include controls for optical amplifiers on pass through light beams.

27. The node of Claim 24, wherein the gain controls include controls for optical amplifiers for adding optical signals to the network.

28. The node of Claim 24, wherein the gain controls are setable by a system installer.

29. The node of Claim 24, wherein the gain controls are dynamically set by node opto-electronics.

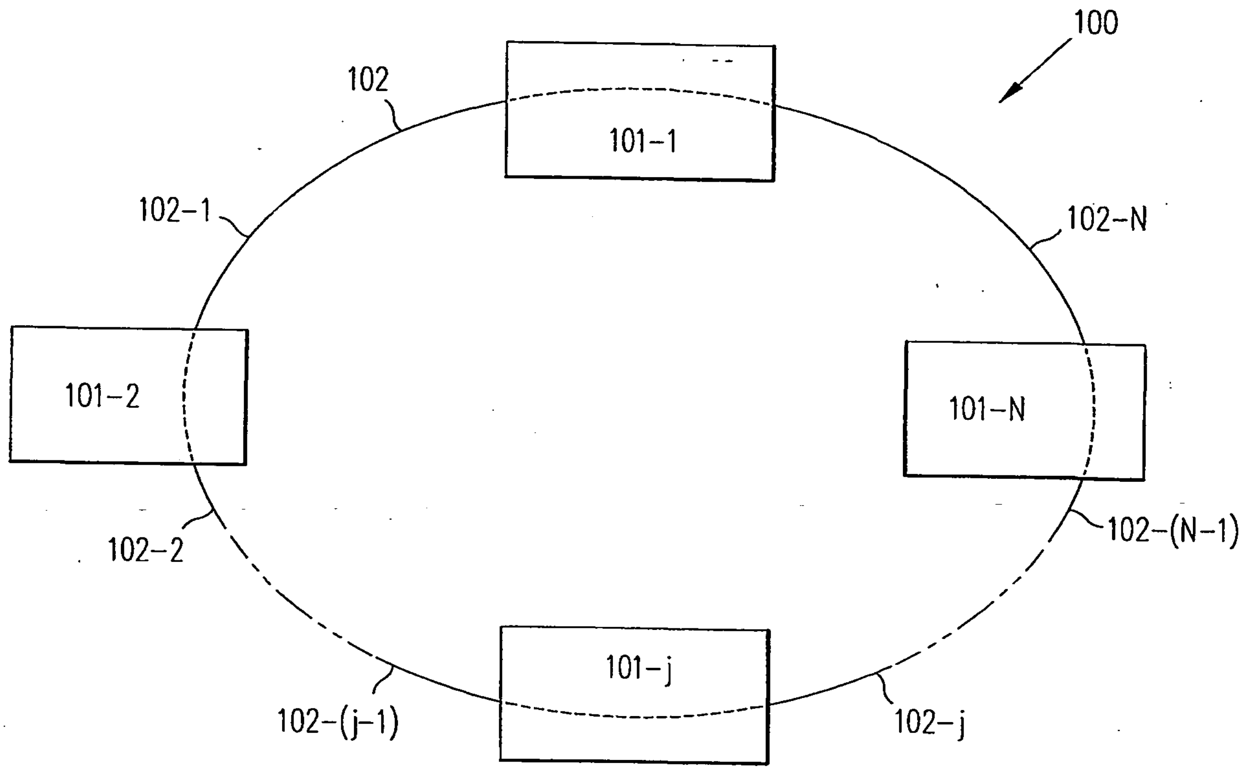
100
102
101-1
102-1
102-N
101-2
101-N
102-2
102-(N-1)
101-j
102-(j-1)
102-j

FIG. 1a

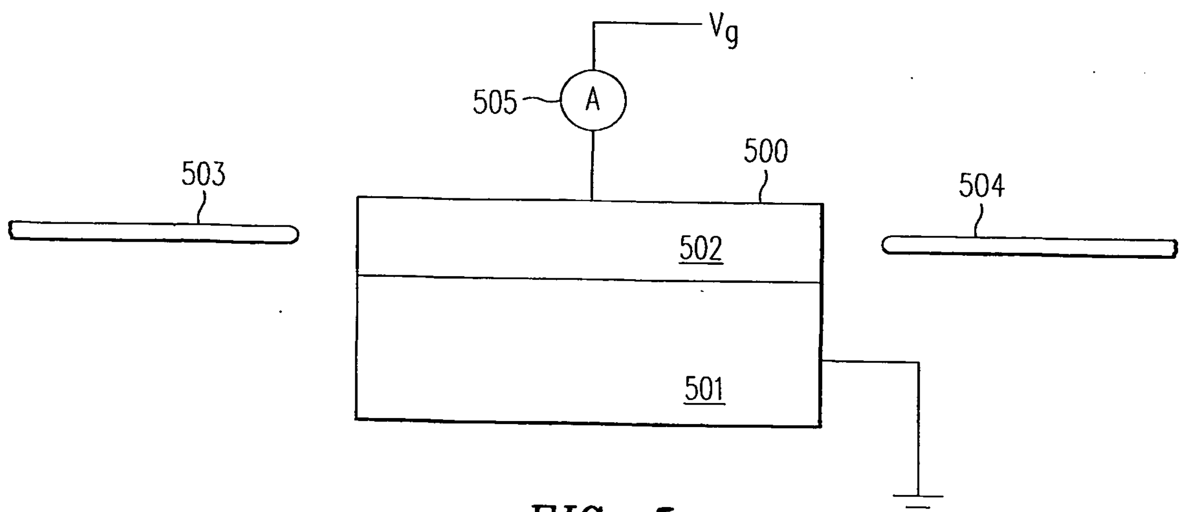
Vg
505
A
500
503
504
502
501

FIG. 5

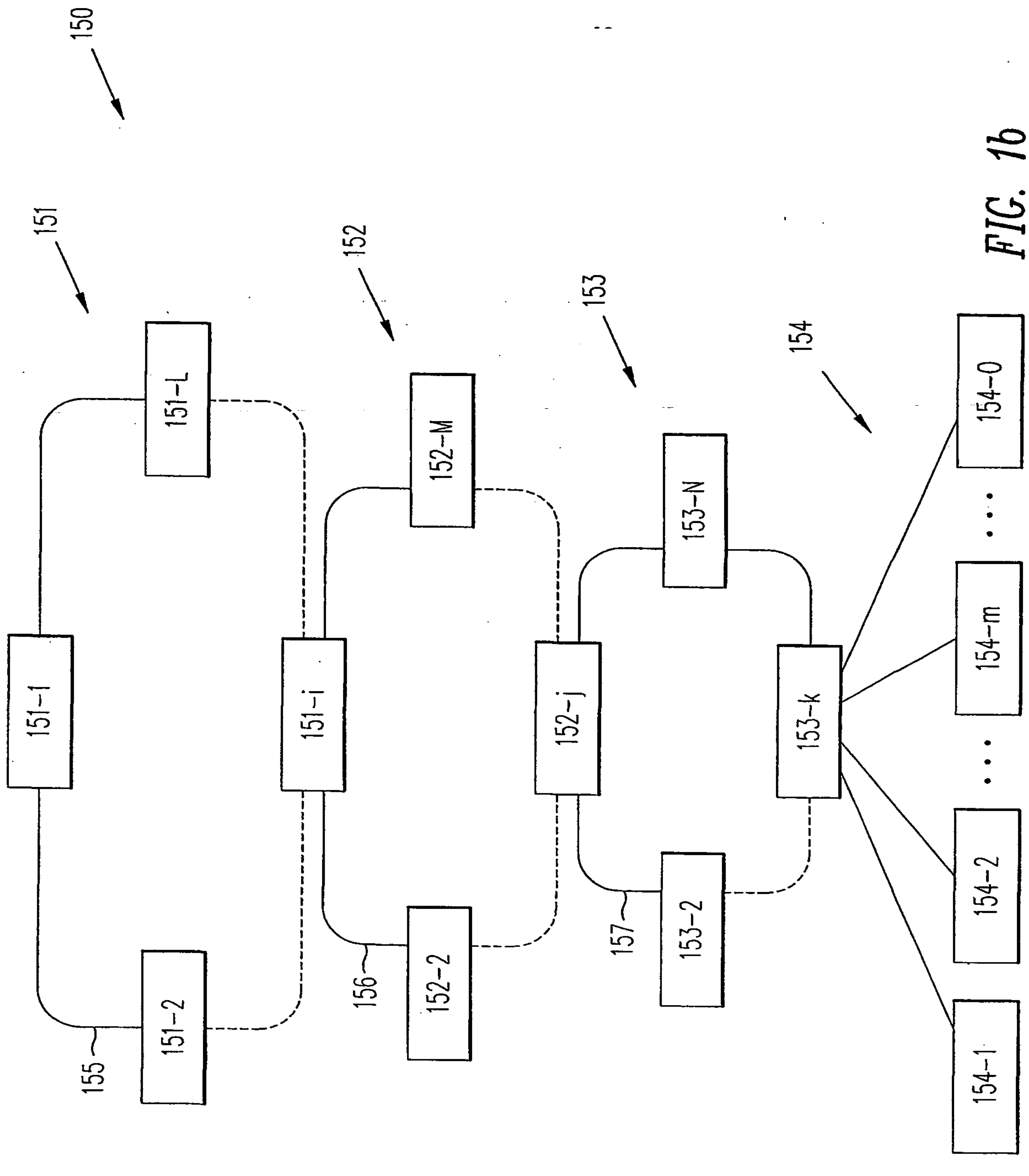
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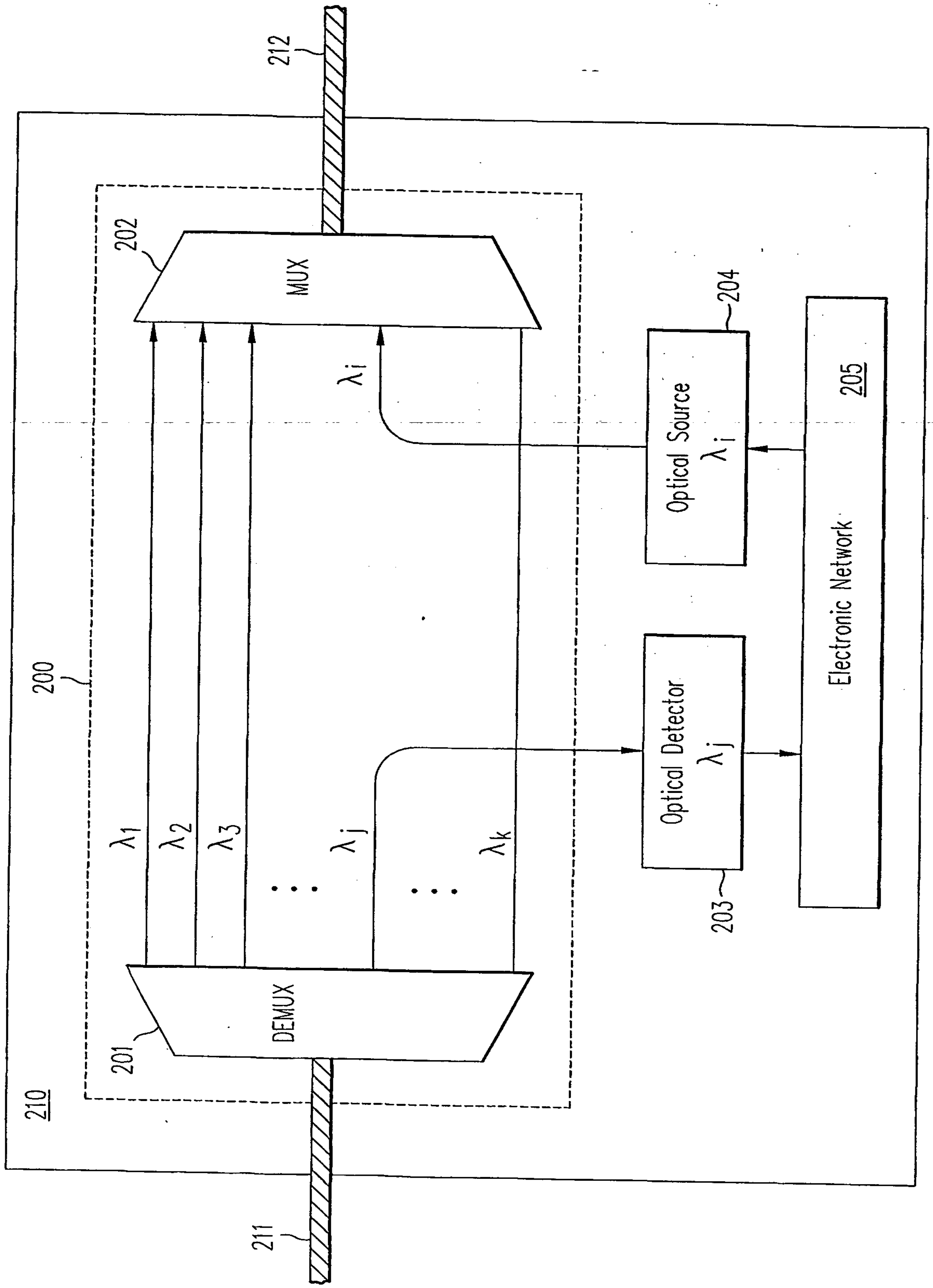
FIG. 1b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λi
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λ1
λ2
λ3
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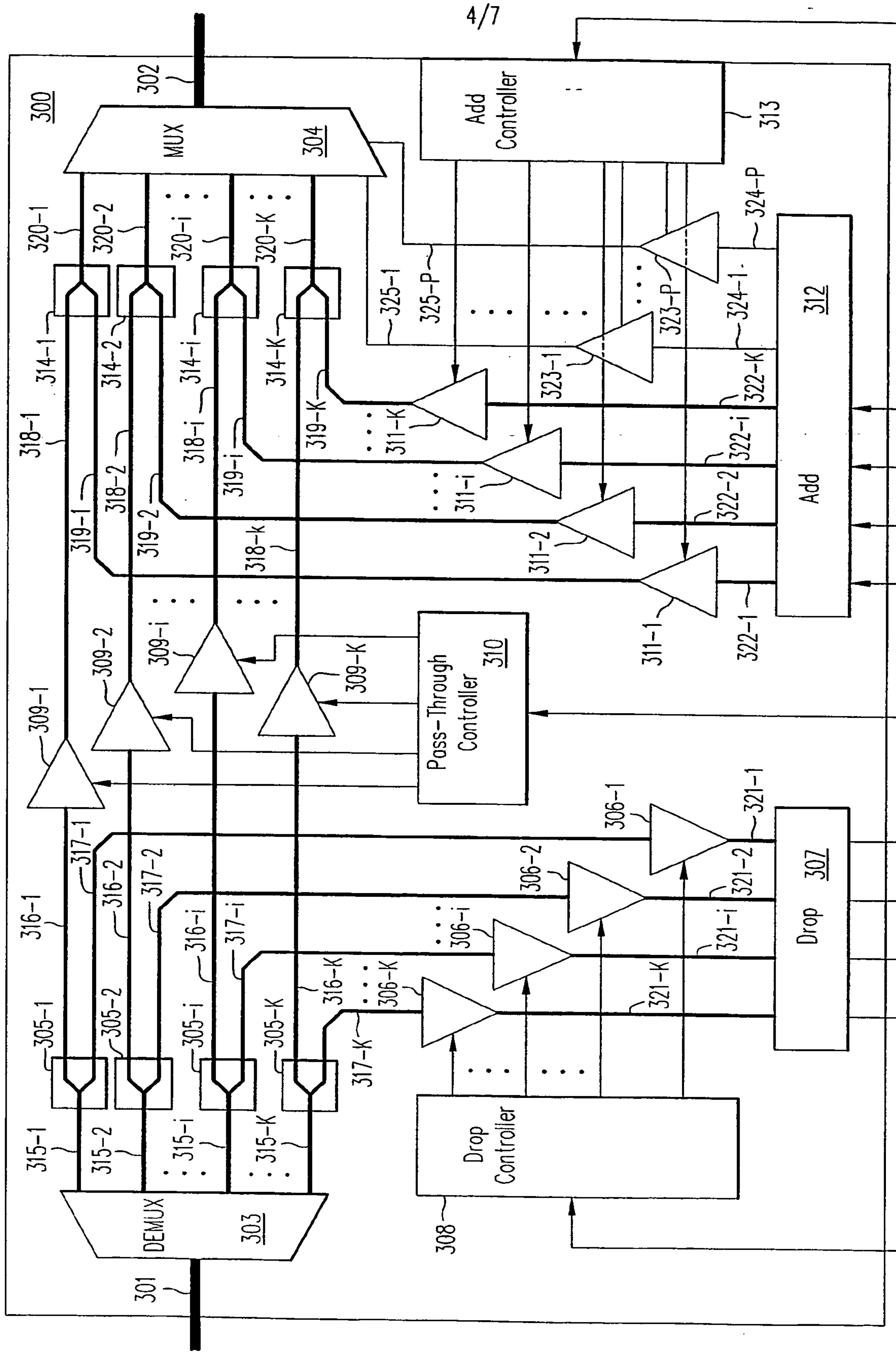
λj
λk
DEMUX
201
210
211

FIG. 2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302
MUX
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Add Controller
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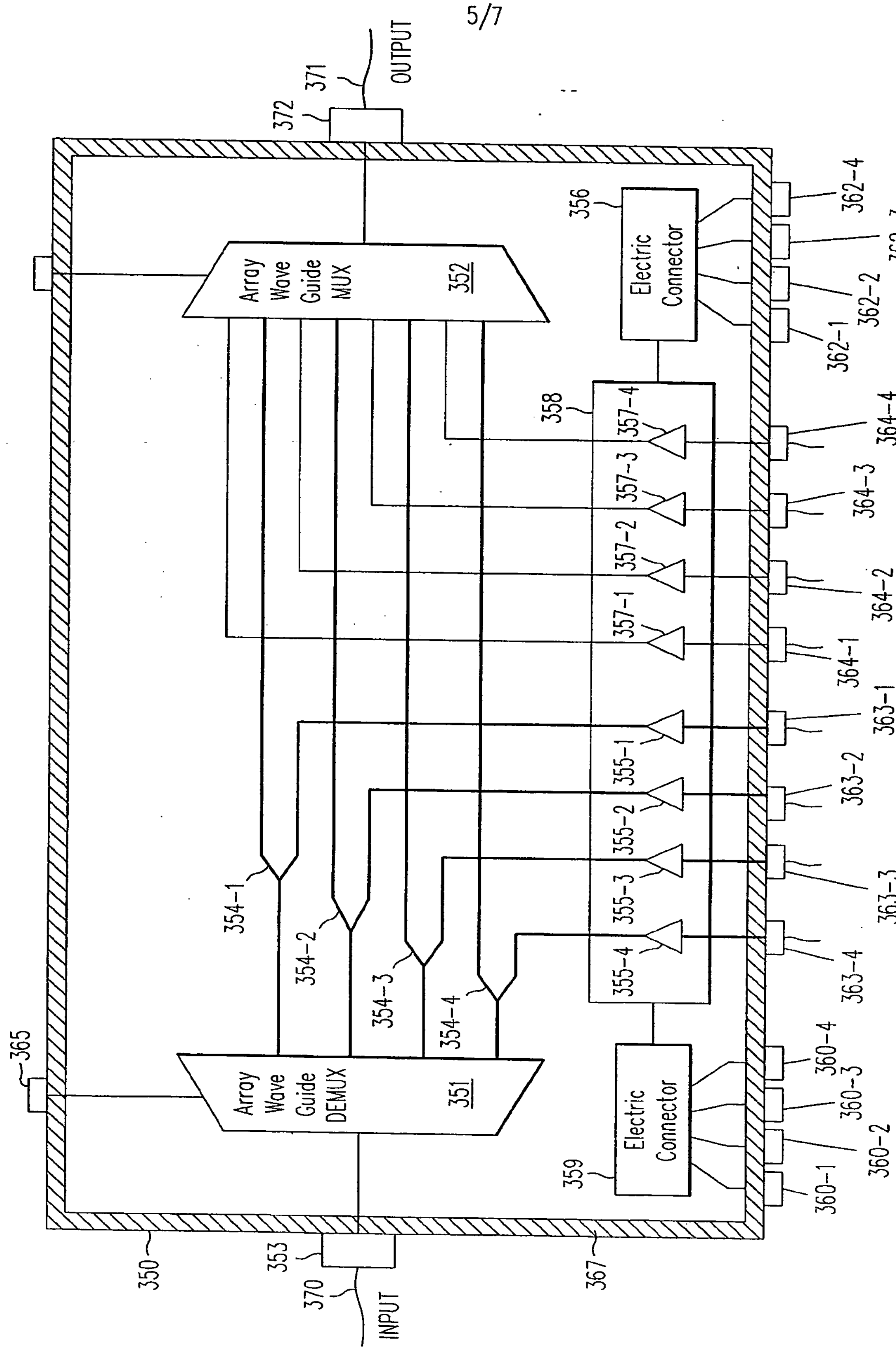
312
Add
Pass-Through Controller
310
Drop
307
Drop Controller
308
DEMUX
303
301

FIG. 3a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INPUT
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353
350
367
365
Array Wave Guide MUX
352
Array Wave Guide DEMUX
351
Electric Connector
356
Electric Connector
359
358
357-1
357-2
357-3
357-4
355-1
355-2
355-3
355-4
354-1
354-2
354-3
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362-4
364-1
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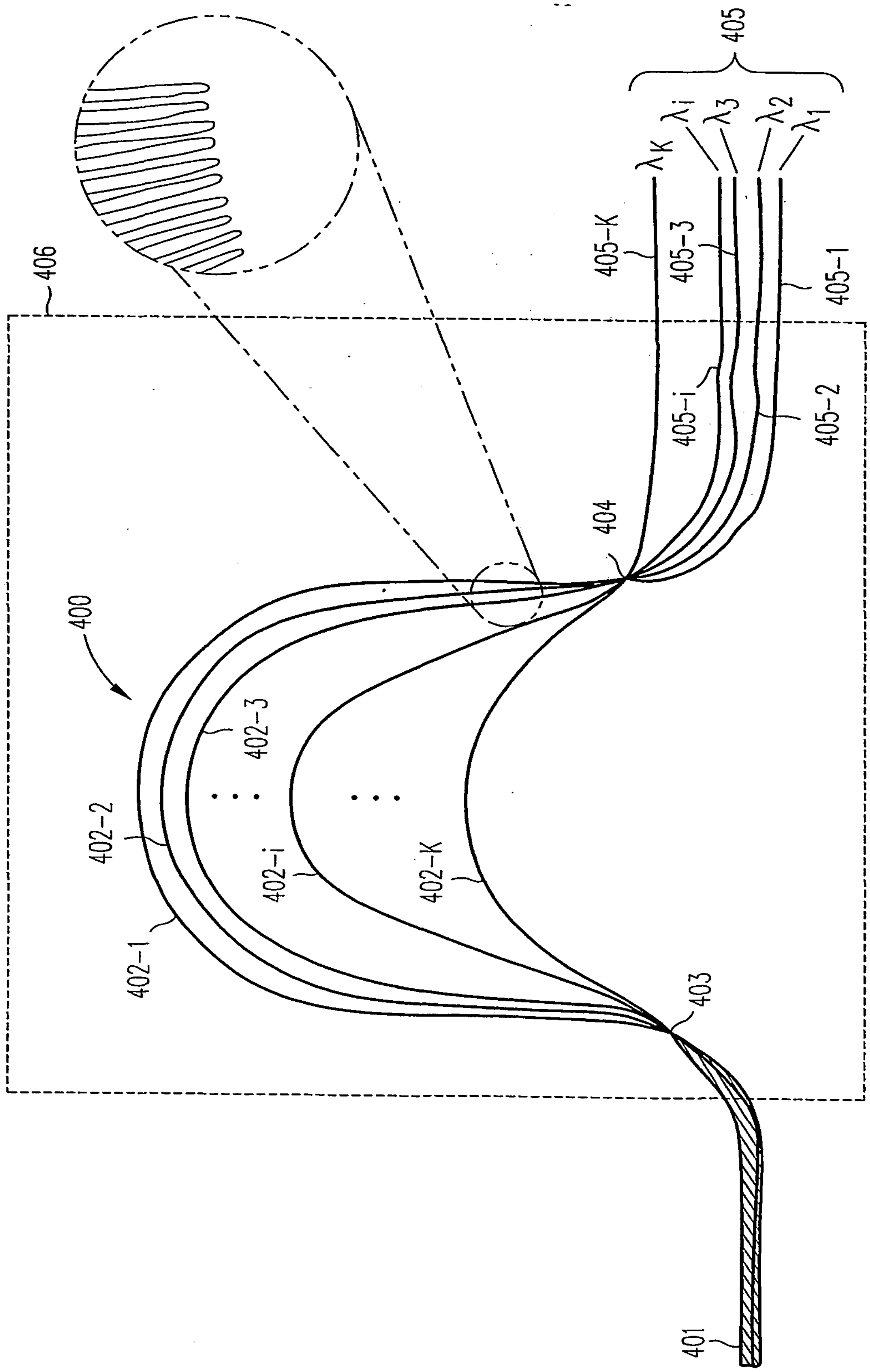
360-4

FIG. 3b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λi
λ3
λ2
λ1
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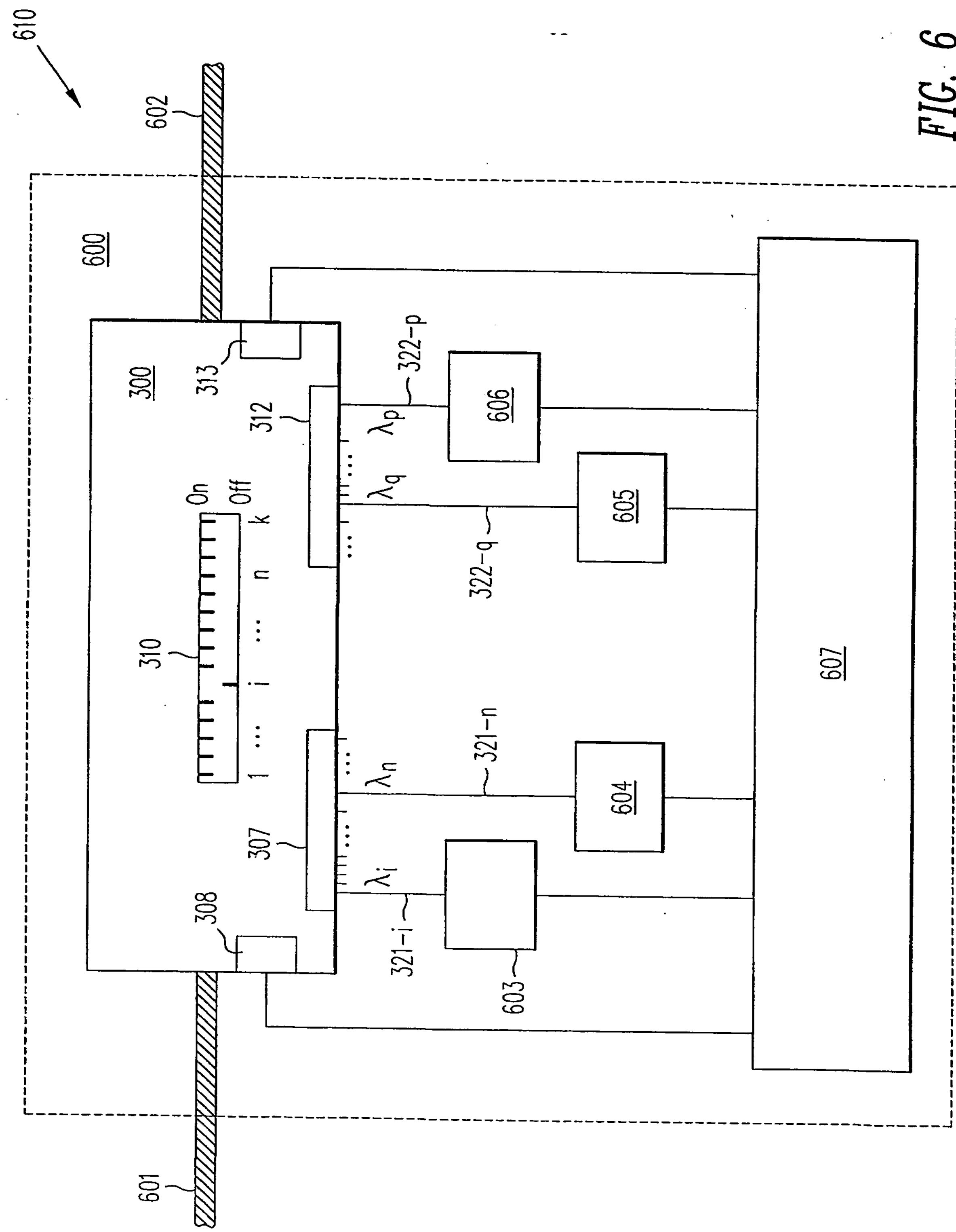
402-1
403
401

FIG. 4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600
300
313
312
322-p
λ_p
606
λ_q
605
322-q
On
Off
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n
310
i
1
307
λ_n
321-n
604
λ_i
308
321-i
603
607
601

FIG. 6

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 01/04086

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04J14/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 43 37 089 A (SIEMENS AG) 4 May 1995 (1995-05-04) column 1, line 3 - line 33 column 3, line 55 -column 4, line 39; figure 2 ---	1-29

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
4 July 2001	10/07/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Roldán Andrade, J